Quality Assurance Project Plan

Project Title: Studying Distribution System Hydraulics and Flow Dynamics to Improve Water Utility Operational Decision Making

Water Distribution System: Nicholasville, Kentucky

Project No.: 02-10-UK

Grant No.: HSHQDC-07-3-00005

Organization: University of Kentucky

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List of Abbreviations

ATSDR- Agency for Toxic Substance and Disease Registry
CR-WQME – Continuous Recording Water Quality Monitoring Equipment
DHS- Department of Homeland Security
DVD – Digital Versatile Disk
Ft- Feet
GIS – Geographical Information System
GPM – Gallons per Minute
ID- Identification
In- Inches
KGS lab- Kentucky Geological Survey Laboratory
KYPIPE – Hydraulic Modeling Software
MCL – Maximum Contaminant Level
MG/L – milligrams per liter
MGD – Million gallons per day
NPT- National Pipe Thread
PRV- Pressure Reducing Valve
PSI – Pounds Per Square Inch
QAPP- Quality Assurance Project Plan
QA/QC – Quality Assurance/ Quality Control
RPD – Relative Percent Difference
SCADA- Supervisory Control and Data Acquisition (SCADA) system
SDG – Sample Delivery Group
SOP- Standard Operating Procedure
SPADNS- (Sulfophenylazo) dihydroxynaphthalene-disulfonate
USEPA – United States Environmental Protection Agency
WDS- Water Distribution Superintendent
WTP – Water Treatment Plant

1.0 Project Management

1.1 Distribution List

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1.2 Project Organization (QA/R-5 A.4)

The roles and responsibilities of project participants are listed below. Refer to Figure 1 for the project organization chart.

Lindell Ormsbee, Director
Kentucky Water Resources Research Institute
University of Kentucky
Role: Project Manager
Responsibilities: Oversee data, Project Manager

L. Sebastian Bryson, Assistant Professor
Department of Civil Engineering
University of Kentucky
Role: Field Manager
Responsibilities: Manage data collection activities, insure data collection conducted consistent with QAPP

Tom Calkins, Public Utilities Director
Nicholasville Water Department
City of Nicholasville
Role: Primary Contact for the Nicholasville Water Department
Responsibilities: Provide assistance in obtaining data for the Nicholasville System. Serve as liaison for Nicholasville personnel

Danny Johnson, Water Distribution Superintendent (WDS)
Nicholasville Water Department
City of Nicholasville
Role: Assist field crews and oversee field testing activities
Responsibilities: Provide personnel for field testing, oversee training of field crew

Jim McDaniel, Operator of Water Treatment Plant
Nicholasville Water Department
City of Nicholasville
Role: WTP Shift 1 Operator
Responsibilities: Help coordinate and collect real time data from the WTP during field testing (i.e. pump discharges, tank water levels).

David Scott, Operator of Water Treatment Plant
Nicholasville Water Department
City of Nicholasville
Role: WTP Shift 2 Operator
Responsibilities: Help coordinate and collect real time data from the WTP during field testing (i.e. pump discharges, tank water levels).

Mr. Morris Maslia
Research Environmental Engineers
Agency for Toxic Substances and Disease Registry (ATSDR)
National Center for Environmental Health
Role: Tracer Analysis Consultant
Responsibilities: Provide guidance on conducting tracer study

Graduate Research Assistant(s)
Department of Civil Engineering
University of Kentucky
Role: Data acquisition oversight
Responsibilities: Collect field data from hydrant testing; troubleshoot field equipment; undertake corrective measures as needed to develop and calibrate hydraulic and water quality models for system

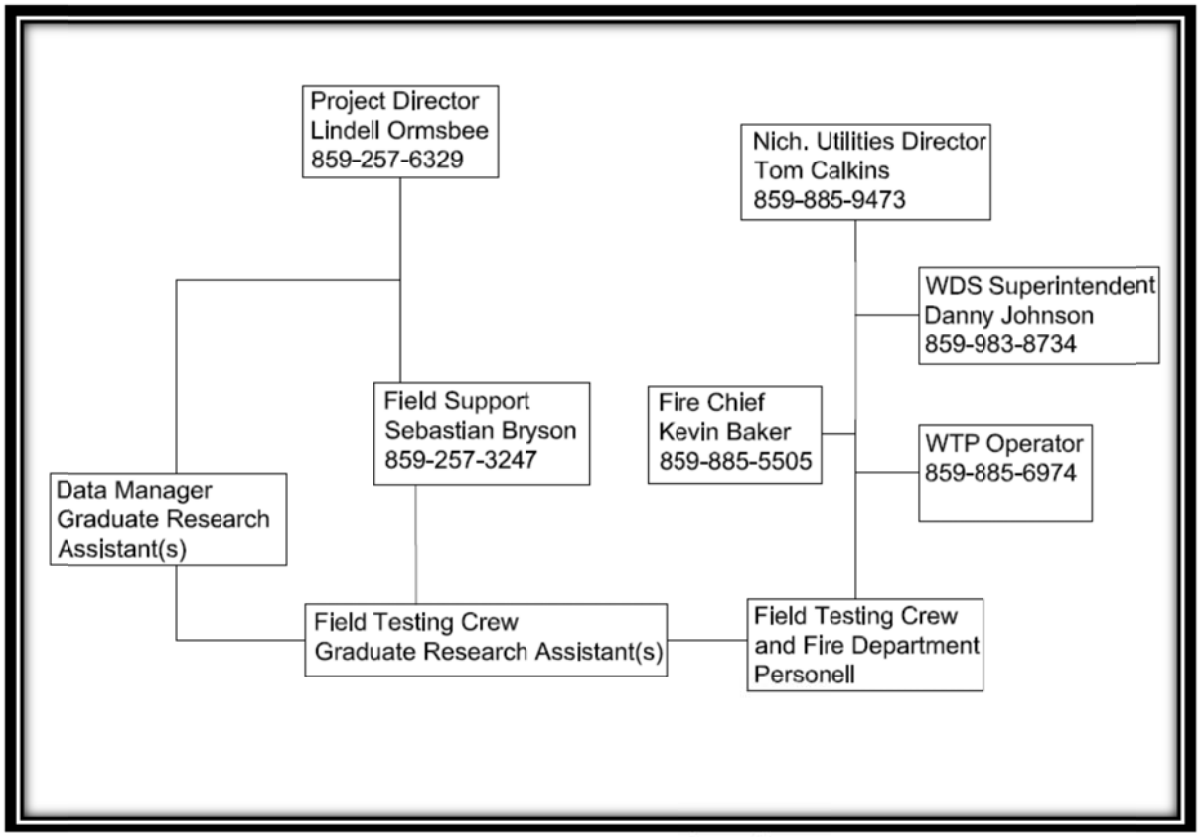

Figure 1 Project Organization Chart

2.0 Problem Definition and Background (QA/R-5 A.5)

2.1 Project Background

The United States Department of Homeland Security (DHS) has established 18 sectors of infrastructure and resource areas that comprise a network of critical physical, cyber, and human assets. One of these sectors is the Water Sector. The Water Sector Research and development working group has stated that water utilities would benefit from a clearer and more consistent understanding of their system flow dynamics. Understanding flow dynamics is important to interpreting water quality measurements and to inform basic operational decision making of the water utility. Such capabilities are critical for utilities to be able to identify when a possible attack has occurred as well as knowing how to respond in the event of such an attack. This research will seek to better understand the impact of water distribution system flow dynamics in addressing such issues.

In particular this project will: (1) test the efficiency and resiliency of the real-time hydraulic/water quality model using stored Supervisory Control and Data Acquisition (SCADA) data in order to understand the potential accuracy of such models, and understand the relationship between observed water quality changes and network flow dynamics, and (2) develop a toolkit for use by water utilities to select the appropriate level of operational tools in support of their operation needs. The toolkit is expected to have the following functionality: (a) a graphical flow dynamic model, (b) guidance with regard to hydraulic sensor placement, and (c) guidance with regard to the appropriate level of technology needed to support their operational needs.

Primary objectives of this project include:

1. Develop an improved understanding about the impact of flow dynamics changes on distribution system water quality, and the potential benefits of using real-time network models to improve operational decisions – including detection and response to potential contamination events.
2. Develop an operational guidance toolkit for use by utilities in selecting the appropriate level of operational tools needed to support of their operational needs.
3. Develop a flow distribution model that will allow small utilities to build a basic graphical schematic of their water distribution system from existing geographical information system (GIS) datasets and to evaluate the distribution of flows across the network in response to basic operational decisions.

This project has been broken down into 12 different project tasks as shown in Table 1. The associated project deliverables are shown in Table 2. This Quality Assurance Project Plan (QAPP) addresses Task 6 of the project which is defined as “develop and calibrate hydraulic and water quality computer models.”

Table 1 Summary of Project Tasks

Task #	Project Task
1	Establishment of an Advisory Group
2	Select Water Utility Partner
3	Survey and Evaluate SCADA Systems
4	Build Laboratory Scale Hydraulic Model of Selected Water Distribution System
5	Develop Graphical Flow Distribution Model
6	Develop and Calibrate Hydraulic and Water Quality Computer Models
7	Quantify Flow and Water Quality Dynamics Through Real-Time Modeling
8	Develop Sensor Placement Guidance
9	Develop Toolkit
10	Test and Evaluate Toolkit
11	Validate Toolkit
12	Write Report

2.2 Problem Definition

The objective of Task 6 of the overall project is to create a calibrated hydraulic and water quality model for the city of Nicholasville Kentucky. This QAPP describes the procedures and rationale for field work in support of stage one of this task which includes the hydraulic modeling. A series of C-factor field tests and fire flow tests will be performed on the water distribution system serving the City of Nicholasville to obtain hydraulic data (i.e. junction pressures, pump station and transmission main flowrates, and tank levels for use in calibrating a KYPIPE hydraulic network computer model for the Nicholasville system.

2.3 Water Distribution System Description

The City of Nicholasville is located in Jessamine County, Kentucky southwest of the City of Lexington. The population was 28,015 for the 2010 census making it the 12th largest city in the state. According to the U.S. census bureau, the city has a total area of 8.5 square miles which is serviced by the Nicholasville Water Treatment plant. The Nicholasville Water Treatment plant is supplied by surface water from Pool 8 of the Kentucky River. The treatment facility is a conventional turbidity removal plant that utilizes chemical coagulation, flocculation, settling and filtration to remove suspended particles from the raw water (See Figure 2). The water distribution plant has a capacity of 9 million gallons per day (MGD). In 2010 the average day demand was approximately 4.4 MGD. Plant operations are monitored and controlled by a computer based Supervisory Control and

Data Acquisition (SCADA) system. The SCADA system monitors and controls pumps, chemical feeds, treatment equipment, flow rates, water levels, etc.

The Nicholasville water distribution system consists of an intake pumping facility, a water treatment plant, a high service pumping facility, and transmission and distribution systems. The treatment plant serves approximately 10,500 retail customers and two wholesale customers. The treated water transmission and distribution system consists of a grid of mains ranging from 2 to 24 inches in diameter and has a total elevated storage of 3 million gallons (3 Tanks). (Nicholasville, 2009-2011) The topography of the area varies from a maximum elevation of ~1042 feet to a minimum elevation of ~560 feet. A schematic of the distribution system is shown in Figure 3.

Figure 2 Nicholasville Water Treatment Plant

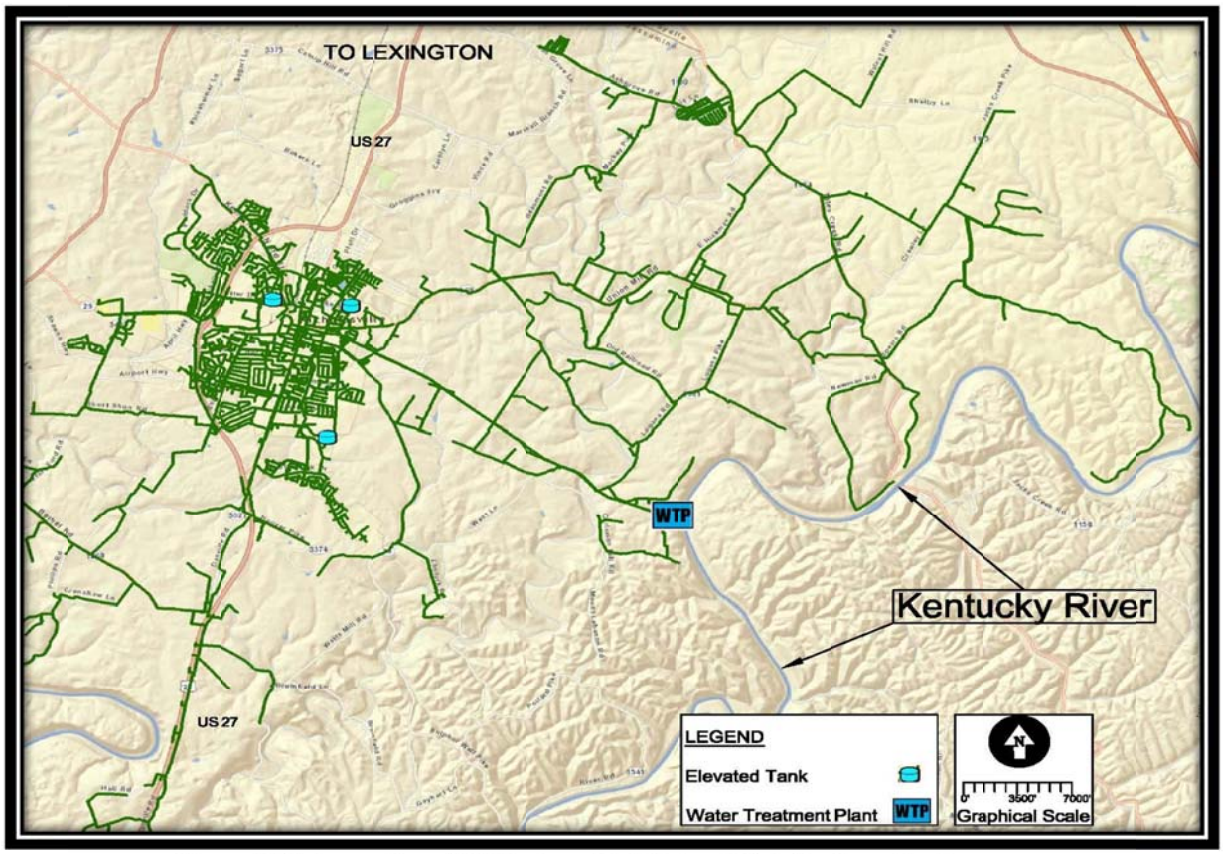

Figure 3 Schematic of Nicholasville Water Distribution System

2.4 Present Day Operations

The Water Treatment Plant (WTP) is located at an elevation of approximately 870 feet msl. The distribution system contains three elevated storage tanks as shown in Figure 3 and summarized in Table 2. When demand causes water levels in these tanks to drop below a minimum water-level mark, high service pumps are turned on at the Nicholasville WTP. The average daily demand during the month of July (peak month) for 2010 for treated water at Nicholasville WTP was 4.4 MGD.

The SCADA system at the Nicholasville WTP provides real time data for pumping operations as well as tank levels, pump flows and pump pressures. This data will be obtained during field testing through communication with the Nicholasville Water Department and will be utilized to help calibrate the hydraulic model.

Table 2 Elevated Storage Tank Identification and Elevations

Elevated Storage Tank Identification, and Elevations*			
Name	Lake Street	Capital Court	Stephens Drive
Size (gallons)	750,000	1,500,000	750,000
Elevation of Bottom of the Tank	1025.75	952.5	966.5
Minimum Level (ft)	1105.75	1111.5	1109.5
Max Level (ft)	1143.75	1151	1148
Shape	Ovaloid	Composite	Ovaloid
Inside Diamter (ft)	60 ft	86 ft	68 ft
*Data from Nicholasville Water Utility Department			

At the Nicholasville WTP, raw water is pumped from the river into a chemical mix basin. Once it has passed through the chemical mix basin it continues through a series of flocculation basins to the settling basins. After the treatment process of coagulation and sedimentation, the clarified water flows into dual media filter beds to remove any remaining solids. After filtration, fluoride is added to the treated water to help improve dental hygiene. Prior to pumping the water into the distribution system, the water is disinfected with chloramines.

Continuous water quality testing is performed at the Nicholasville WTP. Water is tested for turbidity, alkalinity, hardness, iron, manganese, fluoride, pH, corrosiveness and disinfectant residual (Nicholasville, 2009-2011). In July 2010, the monthly average of flouride concentration of samples measured at the tap was 1.09 milligrams per liter (mg/L) while the lowest meaured daily concentration was 1.03 mg/L. In the 2010 Annual Water Quality report the range for fluoride detection was .89 mg/L to 1.23 mg/L (McDaniel, 2010). The chlorine and flouride concentrations were well below Maximum Contaminant Levels (MCL) and therefore are not expected to exceed high levels during a tracer study.

2.5 Rational for Conducting Data Collection

The city of Nicholasville does not have an up-to-date hydraulic or water quality model of their distribution system. The Nicholasville water distribution system was chosen for the purpose of creating a hydraulic and water quality model for the following reasons:

- The Nicholasville system is medium utility/moderate functionality (i.e. services more than 10,000 people and less than 100,000 people).
- The system has an established GIS data set, which includes pipe diameters, lengths, estimated pipe roughness, age, etc.
- WTP operations are monitored and controlled by a computer based SCADA system. This system will give accurate data for tank levels, pump operations, and pump flow rates.

A detailed description of procedures developed to collect hydraulic data during field test and to calibrate a model of the Nicholasville water distribution system is provided in the following section.

2.6 Water Distribution Model Calibration

The availability of reliable network modeling software coupled with affordable computing hardware technology has led to rapid growth in the use of both hydraulic and water quality models of water distribution systems. The validity of these models, however, depends largely on the accuracy of input data and the assumptions made in developing the model. Although carefully developed models tend to have greater control on much of the data associated with the model, certain model parameters exist that are either not readily available or difficult to obtain. Such parameters typically include pipe roughness factors, constituent decay parameters, and the spatial and temporal distribution of water demands. As a result of the difficulty of obtaining economic and reliable measurements of both of these parameters, final model values are normally determined through the process of model calibration (Ormsbee, Lingireddy, 1997). Model calibration involves adjustment of these and other uncertain network model parameters until the model results closely approximate actual observed conditions as measured from field data. In general, a network model calibration effort should encompass seven basic steps: (1) Identification of intended use of the model (2) Identification of calibration model parameters and their initial estimates (3) Model studies to determine the calibration data sources (4) Data collection (5) Macro calibration (6) Sensitivity analysis (7) Micro calibration. Details and procedures pertaining to these seven basic steps can be found in *Calibration of Hydraulic Network Models* by Ormsbee and Lingireddy (1997). A summary of the methodology is provided in Appendix A which will serve as a roadmap for the calibration process to be implemented as part of this project.

2.6.1 C-Factor Tests

C-factor tests are performed to estimate the appropriate C-factor to be used in the hydraulic model. The C-factor represents the roughness of the pipe in the widely used Hazen-Williams friction equation. Typically, such test are performed on a set of pipes that are representative of the range of pipe materials, pipe age, and pipe diameters found in the water system that is being studied.

In a field test, a homogeneous section of pipe between 400 and 1200 feet long is initially isolated. Subsequently, flow, pipe length, and head loss are measured in the field. For the field test a two-gage method will be used. With the two-gage method, pressure is read at hydrants located at the upstream and downstream end of the section and used along with elevation differences between the ends to calculate head loss. The two end hydrants should be spaced far enough apart and there should be sufficient flow so that there is a pressure drop of at least 15 pounds per square inch (psi) (McEnroe et al., 1989). The standard operating procedures for performing a C-factor test are shown in Appendix B.

2.6.2 Fire Flow Tests

Fire flow tests are useful for collecting both discharge and pressure data for use in calibrating hydraulic network models. Such tests are normally conducted using both a normal pressure gauge (for measuring both static and dynamic heads) and a pitot gauge (for use in calculating discharge). In performing a fire flow test, at least two separate hydrants are first selected for use in the data collection effort. One hydrant is identified as the pressure or residual hydrant, whereas the remaining hydrant is identified as the flow hydrant. The AWWA M17 guide- Installation, Field Testing, and Maintenance of Fire Hydrants was used to develop the standard operating procedures for the fire flow test. The standard operating procedures for performing a fire flow test are shown in Appendix C.

In order to obtain sufficient data for an adequate model calibration, it is important that data from several fire flow tests be collected. Before conducting each test, it is also important that the associated system boundary condition data be collected, which includes information on tank levels, pump status, etc. It is a common practice for the local fire departments to conduct hydrant flow tests and record the time of day and corresponding flows and pressures. However, in most cases, such records do not include the boundary conditions associated with each hydrant flow test, as the main purpose for their tests is to rate the fire hydrant and not necessarily for hydraulic calibration. Therefore, care must be taken to avoid hydrant flow data that does not include the associated boundary conditions data. See Appendix C for a sample template for collecting calibration data using hydrant flow tests.

2.6.3 Tracer Studies

A tracer study is a method for observing and measuring the time it takes for water or an associated chemical to travel through a water-distribution system. This information can then be used to further adjust pipe roughness coefficients or calibrate the decay coefficients associated with model chemical constituents (e.g. chlorine). In this type of study, a conservative chemical (i.e. one that does not readily decay over time) is monitored leaving the water supply at the water treatment plant and the resulting concentrations are then measured at specific points in the water distribution system in order to determine the transient time from the water treatment plant pump stations to the point of interest. The tracer chemical can be one that is already being added to the treated water (e.g. fluoride) or one that is injected immediately upstream of the high service pump discharge (e.g. calcium or sodium chloride). Data for use in the tracer study can be collected using a either a continuous and/or grab strategy.

By comparing the observed transient time with the time predicted by the computer model, model parameters can then be adjusted (or calibrated) until the predicted and observed travel times and associated constituent concentrations are equivalent. Additional details on procedures for conducting a tracer study are described in Clark et al. (2004). The

choice of the type of tracer that should be used to conduct a tracer study should be predicated on the following criteria: (1) regulatory requirements, (2) analytical methods for measuring tracer concentration, (3) injection and operational requirements, (4) chemical composition of the finished or treated water, (5) cost of the tracer, and (6) public perception. The advantages and disadvantages of using different types of chemicals for tracer studies are discussed in Clark et al. (2004). For this project, two possible chemicals will be considered: fluoride or calcium chloride The advantages and disadvantages of both approaches are summarized below. The standard operating procedures for performing a tracer study are shown in Appendix D.

2.6.3.1 Fluoride

- The Nicholasville water distribution system currently uses fluoride to fluoridate the treated water therefore the injection of fluoride at the water treatment plant can be shut off until equilibrium concentration conditions can be achieved. Then the fluoride can be re-introduced into the distribution system to achieve a maximum distribution concentration of 2 mg/L.
- Fluoride is a stable compound that can be stored in glass or plastic bottle for at least 7 days when cooled at 39º F without decay.
- The MCL for fluoride is 4 mg/L allowing for a greater factor of safety when the maximum distribution concentration for the tracer test is 1.2 mg/L.
- Some of the continuous fluoride loggers used by Agency for Toxic Substances and Disease Registry (ATSDR) have been unreliable in past tracer studies and will need to be repaired before than can be utilized for testing.
- The water treatment plant already contains fluoride and the WTP staff is familiar with basic protocol for fluoride injections. Less time and money will be needed to train current water treatment plant staff.

2.6.3.2 Calcium Chloride

- Calcium chloride requires only one secondary maximum contaminant level (MCL) standard to be met- chloride at 250 mg/L. (Note: The Kentucky River contains high levels of calcium chloride which will need to be taken into account when performing the tracer study. Typical values of calcium chloride concentrations in the raw water are between 80 mg/L and 120 mg/L).
- The cost of food grade liquid calcium chloride (32% by weight) is inexpensive at approximately $2.54 per gallon and can be delivered in 55 gallon drums.
- An injection pump and tank will need to be purchased in order to perform the tracer study which can be expensive. Training will also have to be provided for water treatment staff.
- Much of the necessary equipment for conducting a tracer study using calcium chloride is available for use from ATSDR thus allowing for a more cost effective data collection effort. ATSDR will be providing approximately 10 dual probe chloride ion and conductivity loggers for use during the tracer study.

3.0 Test Procedures/Measurements and Schedule (QA/R-5 A.6)

3.1 Data Collection

Data to be collected during field testing are summarized in Table 3.

Table 3 Water Distribution System Data Collection Methods

Water Distribution System Data Collection Methods			
Parameter	**Number/Frequency**	**Collection Method**	**Reference**
Pressure	Data Collected during each Test as specified	Hydrant Flow Meters and Hydrant Static Pressure Gages	AWWA M17 and M32 Documents, Appendix B
Tank Water Levels	15-minute interval during testing	SCADA system records[1]	Appendix B and C
Flow From raw water and treated water pumps	15-minute interval during testing	SCADA system records[1]	Appendix B and C
System Operation Procedures (on/off cycling of pumps)	Data collected during each test	Operator system records for on/off cycling events;	Appendix B and C
Fluoride Concentrations	10 Locations - every 15 minutes	Grab sampling at selected hydrants	Appendix E, G and H

Notes:
1. If SCADA is unavailable, manual recording by staff in control room.

Previous records of fire flow testing performed by the Nicholasville Fire Department have been obtained. The Nicholasville Fire Department has previously assigned a hydrant identification (ID) number, location, coefficient, barrel size, direction to open, and other pertinent information for every fire hydrant. This information will aid with quality assurance/quality control (QA/QC) for the hydrant tests and will serve as a basis for labeling and identifying each hydrant.

3.1.1 C-Factor Testing Procedures

C-factor testing procedures will be performed according to the American Water Works Association M32-Computer Modeling of Water Distribution Systems and the general procedures for C-factor tests are provided in Appendix B. Data collection sheets for use in these tests are also provided in Appendix B. C-factor tests will be conducted at 10 separate locations across the water distribution system.

3.1.2 Fire Flow Testing Procedures

Fire flow test procedures will be performed according to American Water Works Association M17- *Installation, Field Testing, and Maintenance of Fire Hydrants* and the general calibration guidance in Appendix A. A summary of the field testing protocol for the fire flow tests is provided in Appendix C. Data collection sheets for use in these tests are also provided in Appendix C. Fire flow tests will be conducted at 10 separate locations across the water distribution system.

3.1.3 Tracer Testing Procedures

Tracer studies will normally involve two basic steps: 1) insertion or "in-stream" regulation of the tracer chemical, and 2) field measurement. Depending upon the type of chemical used in the tracer study, the concentration of the chemical can be controlled by the existing injection system at the water treatment plant (e.g. chlorine or fluoride) or by use of field injection equipment (e.g. calcium or sodium chloride). In the latter case, extreme care must be exercised so as to insure that the injected tracer does not exceed state or federal standards for protecting the environment and public health during the tracer study.

Step input tracer test is where a sudden impact of tracer (either negative or positive) is continuously added at a set concentration, until the same concentration stabilizes at the effluent. For finished water distribution systems, one type of tracer study involves a negative step, followed by a positive step input of fluoride. This can be accomplished by turning off an existing chemical feed, such as fluoride, so the tracer concentration decreases with time down to the background (raw water) fluoride levels. The time it takes for the decreased fluoride levels to reach sampling points through the distribution system is representative of the time it takes for a water parcel to move through the system. Then the chemical feed can be resumed sending a positive step through the distribution system. With a controlled change in chemical addition and one source water locations, eventually all points within the distribution system will have the same tracer concentration as at the tracer feed location at the end of the step-input tracer study. (Daley, 2005)

3.1.3.1 Use of Internal Tracer Chemical (i.e. fluoride)

The fluoride is injected via a peristaltic pump which is controlled by computer system at the Nicholasville water treatment plant. The computer system allows the user to determine the concentration of fluoride to be introduced into the system. During the tracer test the pump can be turned off until the background fluoride concentration can be obtained. Once this concentration has been obtained the peristaltic pump can be turned back on and will pump the user designated fluoride concentration into the system. To assure the public's health and safety, an upper limit fluoride concentration for the tracer study will be set at 1.2 mg/L. This value falls within the range (.7 mg/L to 1.2 mg/L) for the U.S. Public Health Services "optimal level" fluoride content in drinking water and

below the maximum contaminant level goal of 4 mg/L and a secondary maximum contaminant level of 2 mg/L. (Lowes, 2011)

Another approach for injecting fluoride into the distribution system requires a holding tank with water to be mixed with hexafluorosilicic acid. The amount of hexafluorosilicic acid will need to be determined ahead of time to ensure the upper limit fluoride concentration for the tracer study does not exceed 2 mg/L. To estimate the concentration needed for the study, a chemical mass balance computation will need to be conducted using the flow of the WTP, the initial concentration of fluoride in the raw water, and potency of the hexafluorosilicic acid. Once the mixing has occurred the solution is pumped into the delivered water through an injection port using a pump. The second approach is more expensive and requires a great deal of preparation before it can be executed.

3.1.3.2 Use of an External Tracer Chemical (i.e. calcium chloride)

The Nicholasville WTP does not currently use calcium chloride and it would therefore be necessary to create a calcium chloride injection system. The chloride injection system would be similar to the fluoride injection system in which a calcium chloride solution will be mixed with water in a holding tank and then delivered into the system via an injection port using a pump.

The calcium chloride **(**$CaCl_2$) solution that will be used for the tracer study is delivered in 55-gal drums and is 32% $CaCl_2$ by weight. The $CaCl_2$ cannot exceed the current secondary standard MCL of 250 mg/L. In order to meet this standard, the tracer study maximum concentration limit of the $CaCl_2$ solution will be set to 200 mg/L. This will ensure a factor of safety on the concentration limits to ensure the public's health and safety.

3.1.4 Field Sampling Procedures for Tracer Study

Field samples of water quality tracer chemicals are usually collected using either a continuous sampling approach or a grab or batch approach. Often times a mixture of continuous sampling and grab or batch sampling is combined to help provide for quality assurance.

3.1.4.1. Continuous Sampling

An emerging and innovative technology that is a possible alternative to manual sampling is the use of continuous recording water-quality monitoring equipment (CR-WQME) for collecting multiple ion-specific tracer data. The CR-WQME connects directly to a hydrant and can monitor fluoride, chloride or conductivity.

Advantages of using CR-WQME include the ability to record continuously water-quality events (including unplanned events) during a tracer test at small time intervals of 15 minutes or less. This recording provides real-time data when using hand-held logger equipment to query the CR-WQME at each sampling location. Also, the labor needed to conduct the test is reduced.

Disadvantages could include the cost of multiple ion-specific sensors and units for large or complex systems, the effort required to calibrate the equipment by setting up a test-site water-quality laboratory, and the reliability of the equipment for long-term monitoring events.(M.L. Maslia et al., 2005) To gain a better understanding of the advantages and disadvantages of continuous sampling see "Use of Continuous Recording Water-Quality Monitoring Equipment for Conducting Water-Distribution System Tracer Tests: The Good, the Bad, and the Ugly" by M. L. Maslia, J. B. Sautner, C. Valenzuela, W. M. Grayman, M. M. Aral, and J.W. Green, Jr.

3.1.4.2 Grab Sampling

Grab Samples can be obtained from several location in the water distribution system. Different types of sampling locations include fire hydrants, storage tanks, pumping stations, commercial buildings, public buildings and private residences. Grab sampling locations should be selected based upon the application of the sample and the accessibility of the site. It is suggested to obtain drinking water samples in a 100 ml glass or plastic bottle to allow enough volume of the sample so it can be tested multiple times.

Grab sampling is generally done from taps or fire hydrants located at the sampling points. Sampling taps should be free of aerators, hose attachments, strainers and mixing type faucets. The best method for collection a grab sample is to collect the sample directly into the glass or plastic bottle. This eliminates the potential for sample contamination through the use of an intermediate container (Johnston, 2009).

Water samples can also be obtained from fire hydrants that have been fitted with a sampling port or a gate valve. Water should be purged from hydrants to ensure that water from the distribution system is fresh. Previous tracer studies have flowed their hydrants at a constant rate of 2 gallons per minute (gpm) to obtain good representative samples. (Kennedy, 1991).

In order to ensure that a good representative grab sample is obtained, the procedures set forth in *Guideline for Obtaining a Representative Sample for Optimization – Version 5* will be used. This document was produced by the USEPA Technical Support Center. This document has been attached in Appendix H.

Once a grab sample is obtained the fluoride concentration can be obtained in the field via Hach fluoride pocket colorimeters II or transported to the KGS lab for analysis. Field analysis will use the USEPA accepted SPADNS Method or the AccuVac method. Procedures for performing these two methods using the Hach colorimeter can be found in

Appendix E. The KGS lab will use the SW846-9056 method (Appendix G) to perform the analysis. Analyzing the samples in the field provides immediate information on how the study is progressing. This early feedback also helps to determine when the sampling at specific sites can be discontinued.

During the analysis, a quality control sample should be tested, between every 10-15 field samples, with a 1.0 mg/L of fluoride standardized solution. (Daley, 2005) This helps to ensure that the equipment is working properly and that proper testing procedures are being followed.

The grab sampling approach requires a great deal of labor and coordination. Several hundreds of grab samples will need to be collected from various locations. Chain- of-Custody records will need to be filled out and collected by the person collecting the samples. Sample preservation and holding time will need to be taken into account when performing the grab samples. Fluoride is a very stable and can usually be preserved for a few weeks before deterioration begins. Thus it will allow more time to coordinate between collecting the sample, transporting it to the lab, and performing the lab analysis.

3.2 Sampling Locations

Approximately 20 sampling locations have been identified for use in gathering data on hydrant pressures and flows. Approximately ten hydrant locations will be used for C-factor testing and approximately ten hydrants will be used for fire flow testing. Additional testing can be performed as needed. Approximately 10 sites will be used for the tracer study.

3.2.1 C-Factor Testing Locations

In order to determine C-factor sampling locations several factors had to be taken into account. The factors include:

- Age of the pipe being tested- pipes of different ages were selected to help obtain a representative sample of all the pipes.
- Material of the pipe being tested- where possible sampling sites contained different material to help obtain a better Hazen Williams coefficient.
- Accessibility of the hydrant- some hydrant locations were not accessible due to being in a congested area, near hospitals, etc.
- Diameter of the pipe- the size of pipe was taken into account.
- Amount of flow in the pipe- in order to obtain a good sample, you need to produce enough flow to drop the residual pressure at least 15 psi (McEnroe, 1989).

All pipes were categorized into 9 different calibration groups based upon several factors including age, material, and size. These pipes were then assigned an initial roughness value to be placed in the uncalibrated hydraulic model. The goal of the sampling locations was to try and perform a C-factor test for each of the calibration groups. This was not possible due to accessibility of hydrants and lack of available locations for a given calibration group. For example, asbestos cement pipes do not have a suitable site for C-factor testing. Although several calibration groups could not be measured directly, several sites located near each calibration group were selected; such as selecting a site directly off of a large ductile iron pipe. The calibration groups are shown in Table 4 along with the characteristics of each calibration group. Age data for every pipe was not readily available so the average age is an approximate age based upon the current data.

Table 4 Pipe Calibration Group Assignment

Calibration Group	Material	Sizes (in)	~Ave Age	Age Low End (yr)	Age High End (yr)	Total Length of Pipe (ft)	% of Total Length
1	Asbestos Cement	4, 6	40	N/A	40	183550	12.5
2	Asbestos Cement	8,10	40	N/A	40	34963	2.4
3	PVC	2,3,4,6	15	2	30	777635	52.8
4	PVC	8,10,12	5	1	10	207608	14.1
5	Ductile Iron	10,12,16	30	20	45	40677	2.8
6	Ductile Iron	6, 16,20,24	15	15	20	57850	3.9
7	Galvanized and PE	6	N/A	N/A	N/A	18086	1.2
8	Cast Iron	4,6	N/A	N/A	N/A	82071	5.6
9	Cast Iron	8,10,12	40	40	60	69664	4.7

Each C-Factor sampling location has been given a test site ID. Each test site corresponds to 3 hydrants and associated valve(s) to be closed. One hydrant has been designated the flow hydrant where the other two hydrants will be used to collect pressure drops. Each individual hydrant has previously been assigned an ID by the city of Nicholasville and each hydrant has also been given an ID for this project. Table 4 below lists the sampling sites as well as a general location. Figure 4 contains a map of the C-factor sampling locations.

Table 5 C-Factor Sampling Locations

Test Site ID	Pressure Hydrant 1 Pressure Hydrant 2 Flow Hydrant	Nicholasville Hydrant ID	Location	Pipe Diameter	Calibration Group Tested
C-1	P1	1145	Squires Way between Bennett Drive and the end of Squires Way	8	4
	P21	1146		8	
	F1	1147		8	
C-2	P2	786	John C. Watt Drive between Lancaster Road and Delta Drive	6	8
	P22	157		6	
	F2	788		6	
C-3	P3	337	Shun Pike between Alta Drive and W. Brown Street	10	5
	P23	268		10	
	F3	698		10	
C-4	P4	101	S Central Avenue between Royalty Court and Kingsway Drive	6	3
	P24	100		6	
	F4	99		6	
C-5	P5	790	Wilmore Road next to Schools	12	4
	P25	836		12	
	F5	1009		12	
C-6	P6	1158	Harlan Drive between Stanley Drive and Cannonball Drive	8	4
	P26	989		8	
	F6	988		8	
C-7	P7	403	Bell Place between Hillbrook Drive and Cloverdale Drive	8	4
	P27	717		8	
	F7	390		8	
C-8	P8	1266	Bernie Trail near the intersection with Lebeau Drive	8	4
	P28	1195		8	
	F8	1194		8	
C-9	P9	406	Hawthorne Drive near the intersection of Old Ky-29	6	3
	P29	670		6	
	F9	671		6	
C-10	P10	239	Weil Lane between Linden Lane and Beacon Hill	6	3
	P30	240		6	
	F10	287		6	

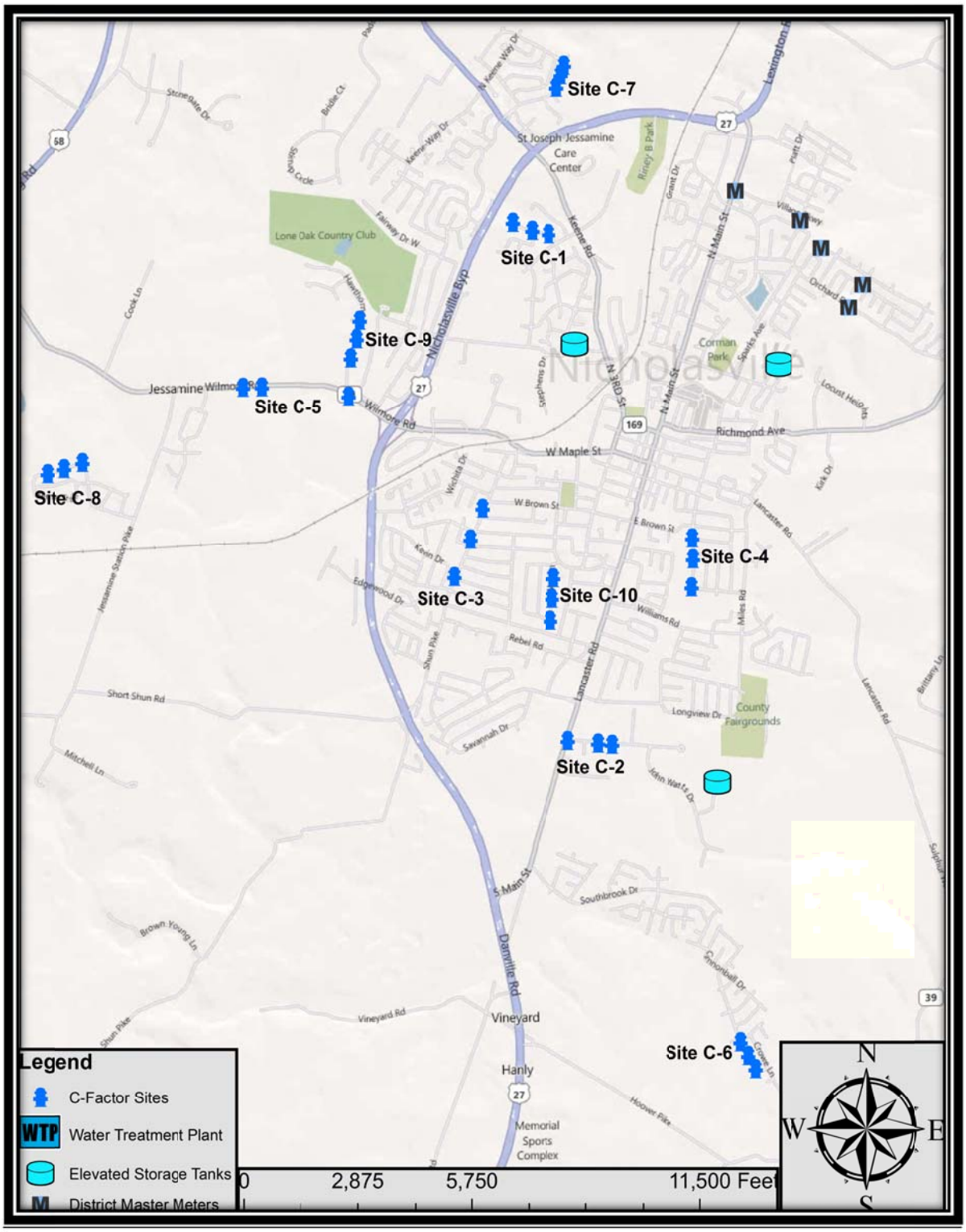

Figure 4 Site Locations for C-Factor Testing

3.2.2 Fire Flow Testing Locations

In order to determine fire flow sampling locations several factors had to be taken into account. The factors include:

- Distance from boundary conditions- it is suggested that the testing site take place as far away from boundary conditions such as tanks, WTP, Pressure reducing valves (PRV) to increase the head loss in the system (Walski, Advanced Water Distribution Modeling and Management , 2000).
- Accessibility of the hydrant- some hydrant locations were not accessible due to being in a congested area, near hospitals, etc.
- Expected head loss- Walski suggests a head loss at least five times as large as the error in the head loss measuring device (Walski, Model Calibration Data: The Good, the Bad and the useless, 2000) .
- Amount of flow in the pipe- in order to obtain a good sample you need to produce enough flow to drop the residual pressure at least 10 psi (AWWA, 1999).

In general, fire flow testing should occur during peak flow conditions to ensure that adequate pressure drops are created. If sampling occurs during low flow conditions, the velocities may not be high enough to produce enough head loss for a good calibration.

Each fire flow sampling location has been given a test site ID. Each test site contains 2 hydrants. One hydrant is the designated flow hydrant and the other hydrant is the residual hydrant. Each individual hydrant has previously been assigned an ID by the city of Nicholasville and each hydrant has also been given an ID for this project. Table 6 lists the sampling sites as well as general locations. Figure 5 contains a map of the sampling locations.

Table 6 Fire Flow Sampling Locations

Test Site ID	Residual Hydrant / Flow Hydrant	Nicholasville Hydrant ID	Location	Pipe Diameter
FF-1	R1	805	On Juniper Drive between Arbee Drive	8
	FH101	799		8
FF-2	R2	236	On Kimberly Heights Drive near the intersection of Shreveport Drive	8
	FH102	478		8
FF-3	R3	1129	Between 144 Brome Drive and 124 Brome Drive	8
	FH103	1130		8
FF-4	R4	435	South Creek Drive Near the Insersection of Bridge Side Drive	6
	FH104	564		6
FF-5	R5	462	Lindsey Drive	6
	FH105	463		6
FF-6	R6	192	South 5th Street between Broadway Street and West Maple Street	8
	FH106	214		8
FF-7	R7	681	Christopher Drive between Kevin Drive and Quinn Drive	8
	FH107	514		8
FF-8	R8	476	Intersection of Bell Lawn and Hillbrook Drive	10
	FH108	489		6
FF-9	R9	1184	On Dawson Pass between the 120 Dawson Pass and Curtis Ford Trail	8
	FH109	1183		8
FF-10	R10	45	E Oak Street Between Scott Alley and N York Street	8
	FH110	44		8

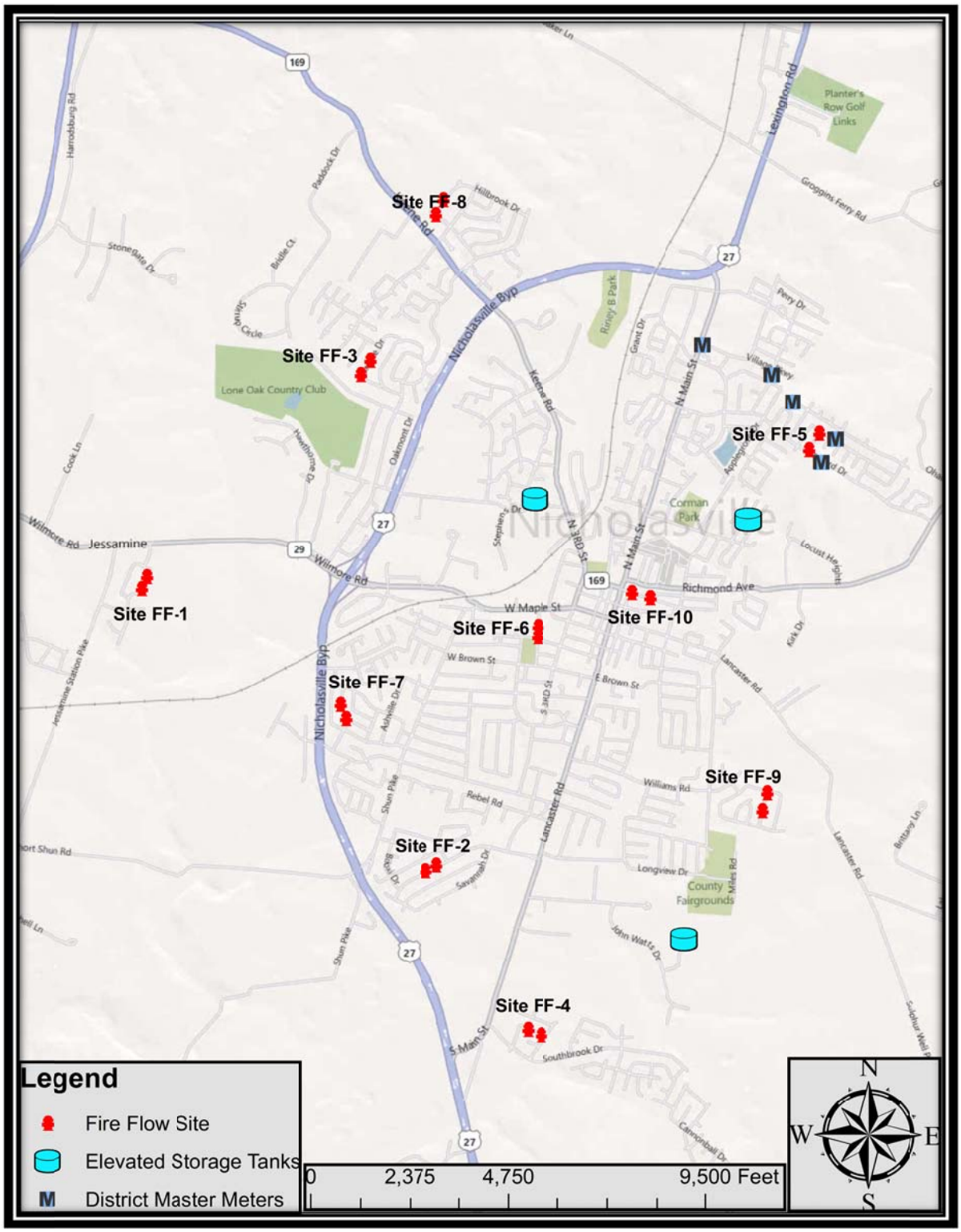

Figure 5 Site Locations for Fire Flow Testing

3.2.2 Tracer Study Testing Locations

The sampling locations for the tracer study have not been selected due to inadequate hydraulic data. The sampling locations will depend a great deal on the information taken from the hydraulic model of the Nicholasville system. Once the hydraulic model is complete, sampling sites will then be selected based upon several factors. These factors include:

- Geographical distribution throughout the distribution system. Sample sites will be spread out among the distribution system.
- Previous or anticipated water quality data and knowledge of the flow regimes through the existing system will be taken into account in choosing the sites and sample intervals.
- The accessibility of the sample site will be taken into account. It would be ideal to have 24 hour access to each sampling location.
- Sampling sites located along the main flow path will be given priority so the data would be useful for a better hydraulic model calibration.
- The amount of demand/customers served near a certain hydrant will be taken into account. Areas of low water usage may affect the quality of the sample due to lack of water circulation. Areas with large commercial users such as a golf course may impact the study events. (EPA, 2005)
- Areas with historically low or fluctuating fluoride levels will be considered. Previous water quality tests indicate some areas do not have good turnover in water quality. These sites would not be ideal for a tracer study.
- Proximity to tanks and water treatment plant will be taken into account. The impacts of the mixing in tanks can be determined by sampling the inflow and outflow lines.
- Freezing is an issue that should be taken into account. If water is flowed directly into the street or sidewalks during cold weather, ice could develop and become a hazard for the public.
- Previous water quality sampling sites will be taken into account since the data may be used for comparison or analysis.

The planned number of sampling locations that will be selected is approximately 10 sites. This is subject to change as more information is gathered on the hydraulics of the system.

3.3 Scheduling

The schedule of activities prior to and during the field testing is listed in Table 7. The current schedule should only serve as a basis for planned events. The current expected begin and completion dates are subject to change based upon circumstances that arise during the duration of the project.

Once the final draft of the Standard Operating Procedure (SOP) and QAPP is approved, a meeting will take place to discuss the procedures and necessary actions needed for training and equipment acquisition for fire flow and C-factor testing. After proper training and equipment calibration has occurred, the fire flow test and C-factor testing will commence. The scheduling of hydrant tests will be determined based upon availability of personnel and ability of the system to handle hydrant testing.

Table 7 Preliminary Schedule of Events

Preliminary Schedule for Calibration of Hydraulic Network				
Task	Milestone	Expected Begin Date	Expected Completion Date	Personnel Responsible
1	Finalize Draft of Nicholasville Water Distribution Hydraulic Field Testing QAPP	5/23/2011	9/30/2011	Lindell Ormsbee /GS
2	Meet with all Personell and Discuss Testing Procedures and Protocols	9/21/2011	9/23/2011	Sebastian Bryson, Kevin Baker/GS/Fire Department Personnel
2	Train Fire Flow and C-Factor Testing Personnel	9/26/2011	9/30/2011	Kevin Baker/GS
3	Perform C-Factor Testing	10/10/2011	10/17/2011	Fire Dept/ GS
4	Perform Fire Flow Testing	10/17/2011	10/21/2011	Fire Dept/ GS
5	Record Data into Database	10/21/2011	11/2/2011	Data Manager
6	Finalize Hydraulic Model	10/2/2011	11/2/2011	Data Manager/GS
7	Meet with all Personell and Discuss Tracer Testing Protocol	3/1/2012	3/8/2012	Lindell Ormsbee, Sebastian Bryson/GS/Fire Dept/WTP
8	Install and calibrate equipment for Tracer Study	3/20/2012	3/25/2012	Fire Dept/ GS
9	Shut down Water Treatment Plant Fluoride Concentration	3/25/2012	3/30/2012	WTP
10	Collect Grab Samples of Tracer	3/31/2012	4/2/2012	Fire Dept/ GS/ WTP
11	Finalize Water Quality Model	4/2/2012	5/2/2012	Data Manager/ GS
12	Write Report	4/2/2012	5/17/2012	Lindell Ormsbee/GS
Notes: The Schedule is Tentative and is subject to change				
GS = Graduate Students Fire Dept = Fire Department Personnel WTP = Water Treatment Plant Staff				

3.4. Test Equipment/Special Personnel Training

Equipment utilized for the test will enable the gathering of data for hydraulic and water quality calibration of the water distribution system. Listed below is a description of the monitoring equipment and methods by which they will be used to perform the C-factor test, fire flow tests and tracer study. See Appendix F for a complete list as well as photos of all equipment to be used.

3.4.1 Hydrant Flow gauge

Hydrant flow data will be gathered using the Pollard hydrant flow gage (see Figure F.1 in Appendix F). Hydrant flow data will be measured for the fire flow test as well as for the C-factor test. During the test, hydrant flow data will be recorded by viewing the flow gage and recording the results. These observations will be confirmed by a second field person before recording. Pressure snubbers have also been purchased to increase the life of the gauges by absorbing all the shock and pulsations that can damage pressure instruments.

3.4.2 Hydrant Static Pressure Gage

Static and residual pressures will be recorded using a Pollard hydrant static pressure gage (see Figure F.2 in Appendix F). The fire hydrant gage comes with a bleeder valve allowing the user to vent air and water from the hydrant before taking readings. Once installed on the hydrant, the hydrant static pressure gage can be used to record the residual pressures by visually recording the gage data.

3.4.3 Continuous Pressure Recorder

Tank levels can be measured via a Pollard continuous pressure recorder (see Figure F.3 in Appendix F). The continuous pressure recorder will be placed on a hydrant near or below the water tank level and can record pressures every 10 seconds. The data can then be extracted via cables or a flash drive onto a computer and stored for further use. The continuous pressure recorder can also be used in other applications similar to the hydrant static pressure gauge. In some instances the continuous pressure recorder may be placed in other areas throughout the system to help monitor pressures.

3.4.4 Dechlorinating Diffuser

For hydrant flushing applications that require dechlorination of discharged water, a dechlorinating diffuser will be used (see Figure F.4 in Appendix F). The dechlorinating diffuser contains a flow measurement pitot. The device traps debris, diffuses discharge, neutralizes chlorine and chloramine in potable water and connects easily to a hydrant or fire hose.

3.4.5 Hach Fluoride Pocket Colorimeter II Testing Kit

The Hach Fluoride Pocket Colorimeter II (see Figure F.7 in Appendix F) is designed to go anywhere and is suitable for extended field work or quick on the spot process monitoring. The colorimeter uses the AccuVac method or the SPADNS method for determining the fluoride concentration of a sample. Both these methods are EPA approved. Once a 100 ml grab sample has been obtained, approximately 10 ml needs to be taken from the sample to perform the SPADNS method and approximately 50 mL is needed for the AccuVac method. Once the test is performed using the colorimeter, the fluoride concentration appears on the screen in mg/L.

3.4.6 Gate Valves

Gate valve (see Figure F.15 in Appendix F) can be applied to individual hydrants and opened or closed as needed to help collect field grab samples. Since grab sampling will be taken at hydrant, it is important to obtain the water quality sample from the transmission main and not from the water collected near the hydrant. To help improve sampling, the gate valve can be opened so water is allowed to flow. This will ensure the sample collected is representative of the water distribution system.

3.4.7 Dual Probe Fluoride/Chloride Ion and Conductivity Loggers

To record fluoride concentrations and conductivity data simultaneously, the HORIBA W-23XD dual probe, multi-parameter water quality monitoring system (see Figure F.17-F.19 in Appendix F) will be used. This is the same equipment used by Agency for Toxic Substances and Disease Registry (ATSDR) for their tracer study at Camp Lejeune. This system consists of a duel probe ion detector, (fluoride and chloride ion sensors and conductivity sensor) and a flow cell that fits the double probe W-23XD. The probe and flow cell will be housed in a plastic protective container which is a standard 5-gallon water jug. Water will pass through the flow cell by attaching a Dixon A7893 hydrant adapter kit to the sampling location hydrant. The adapter kit will be configured with a 1/4 National Pipe Thread (NPT) brass “T” and two 1/4-inch ball valves on each side of the brass “T”. One valve will be used to control flow into the flow cell and the other valve will be used to turn water on and off when obtaining grab samples from the hydrant. The complete configuration consisting of the HORIBA W-23XD probe, flow cell, and 5-gallon plastic protective water jug will be secured to the hydrant by means of a chain and lock. There will be a continuous discharge of water coming from the flow cell and plastic protective container (approximately 1–2 gallons per minute). To monitor and download fluoride and chloride concentration and conductivity data, the HORIBA water-quality control unit is attached to the sensor probe using a cable. With the configuration described above, the data logger continues to record data while real-time data values can be viewed using the HORIBA water-quality control unit and grab samples can be obtained for QA/QC analyses.

3.4.8 Single Probe Conductivity Loggers

The cost of the dual probe loggers described above, and the need to have additional sampling locations, a single probe continuous recording logger will be used to record conductivity at some hydrant locations. The chloride concentration can be determined by measuring the conductivity and then using conductivity versus chloride calibration curve that has been determined in the laboratory. The water quality monitoring system that will be used to record conductivity at sample hydrants is the HORIBA 21XD single-probe water quality measurement logger (See Figure F.20 in Appendix F). The single probe unit will be attached to the sampling hydrant in the same manner as the discussed above for the dual probe unit. To monitor and download conductivity data, the HORIBA water-quality control unit is attached to the sensor probe using a cable as previously described.

3.4.9 Grab Sampling Bottles

100 mL or 250 mL plastic bottles (See Figure F.16 in Appendix F) will be used for collecting grab samples of the tracer's concentration. The 100ml plastics bottles will be provided by the lab at UK.

3.5 Special Personnel Training

The most current, approved QAPP will be distributed to all project personnel via email prior to data collection. All personnel shall read and be familiar with all the SOPs and associated QA/QC protocols.

Prior to any field data collection, all graduate research students will view a short video produced by American Water Works Association entitled Field Guide: Hydrant Flow Tests. The video covers the basic protocol and necessary steps for proper fire flow testing.

Additional training for fire-flow testing and C-factor testing will be performed by the Nicholasville Water and Fire Department. The Nicholasville Water and Fire Department has performed numerous hydrant tests on the Nicholasville system and is knowledgeable of both the basic protocols and procedures for such tests as well as any potential problem areas within the system. Water and Fire Department personnel will help provide instruction and assist with the training of graduate research students provided by the University of Kentucky.

Graduate research students will also be equipped with the information and be given guidance on the proper procedures for collecting grab sampling and operating the equipment.

3.6 Communication and Contingencies

During a fire flow and C-factor testing the sampling sites will be adequately marked by orange cones to warn the public that caution should be taken around the testing site. Possible problems associated with hydrant testing such as dumping chlorines and chloramines into a sensitive environment, downstream flooding, mechanical problems with the water distribution system, poor instrumentation and inaccurate record keeping have been documented along with actions to remedy and prevent such problems (see Appendix B). Chlorinated water shall be disposed in a manner that shall not violate 401 KAR 10:031.

During the tracer study all sampling hydrants will be marked with signage providing information to local residents of the tracer test and who they should contact with any questions.

Each member of the field testing crew will have in their possession at all times during the hydraulic calibration a cellular telephone or two-way radio communication device. Each member will have a complete list of all cellular telephone numbers and radio frequencies. This will allow for immediate communication during the testing and will allow for a quick response in the event of an emergency.

The health and safety of the public is extremely important in conducting the field testing procedures. A Nicholasville WTP staff operator shall be present while the hydrants are being flowed. The WTP staff operator will frequently monitor the flow in the system and if anything unusual is observed, the operator will take the proper course of action to remedy the situation.

3.7 Health and Safety Issues

Prior to testing, all relevant local authorities (i.e. Nicholasville city government, Nicholasville police department, Nicholasville fire department) will be notified of the location, time and extent of field sampling. Emergency contact numbers for the field team shall be provided to all relevant authorities. The team will also have in their possession emergency contact number for all relevant agencies. All traffic regulations, procedures, and laws will be strictly observed by teams when driving vehicles from site to site. Each vehicle will be equipped with a first aid kit. Because of the duration of time that field teams may be exposed to the sun, sun block cream will be provided to protect their skin. All field personnel will wear reflective vests during the tests as well as proper clothing and shoes to protect against injury.

If it is determined that the general public should be made aware of the testing activities proper communication will be issued such as a letter of notice or through flyers to be distributed prior to the day of testing. Field testing teams will have proper identification

on them at all times in the field in case a situation arises where a field member will need to be identified by local residents.

Before any tests that involve the opening and flushing of hydrants, the location of the tests should be approved by local water utility and fire department officials to insure that system pressures are not lowered below a level that could induce cross contamination of the system by sucking contaminants into the distribution system.

Before any tests that involve the opening and flushing of hydrants, the field team should first survey the area and determine the direction of flow and ultimate disposition of any discharges so as to prevent any safety issues or loss or damage of private property. In such cases, it may be necessary to survey the area with a survey instrument (i.e. level) to confirm the anticipated downstream gradient of the area. Where warranted, it may be necessary to employ a hydrant diffuser or a 4 x 8 piece of plywood to avoid damage to green space as a result of the discharging jet of water from the fire hydrant.

Prior to opening any hydrant nozzle, the field crew should confirm that the hydrant valve is closed. As an added precaution, the nozzle cap should be removed with a hydrant wrench with the field personnel standing to the side so as to prevent injury from a hydrant cap shooting off in the event the hydrant valve was actually open. In opening any hydrant, care should be used to open the hydrant slowly and in incremental steps so as to minimize any transient pressure issues in the distribution system. Prior to installing any instruments (i.e. flow/pressure gage) on the discharge nozzle of the hydrant, the hydrant should first be opened and flowed for a couple of minutes to remove any particles or rust that may have accumulated in the hydrant service line and barrel. Once this has been done, the hydrant valve should be closed and the instruments installed prior to opening the hydrant a second time for use in data collection.

The health and safety of the public is extremely important in conducting the tracer study. A Nicholasville WTP staff operator shall be present during the duration of the tracer study to monitor the injection of tracer solution and the resulting concentrations in delivered water.

The tracer field team and Nicholasville utility personnel will frequently monitor the fluoride levels at the sampling hydrant locations to assure that the fluoride concentrations are below 2mg/L. If it is discovered that the sampling hydrant exceeds these levels the project officer will immediately be notified as to the resulting concentrations, the sampling hydrant identification, and how the exceeding concentration was obtained. The project officer will discuss these findings with the Nicholasville utility staff. Based upon the concentrations found the following procedures should be followed.

(1) Fluoride concentrations exceeding 1.2 mg/L and less than 2 mg/L
   a. More frequent monitoring of continuous recording loggers will begin and additional QA/QC grab samples will be obtained from sampling to more closely assess if there is a trend in increasing fluoride concentrations.
   b. Verification of grab samples should be taken at the sampling hydrant that exceeded the 1.2 mg/L and taken to the lab for an analysis.
   c. If the additional grab samples indicate concentrations are within acceptable limits (1.2 mg/L or less) then the sampling frequency may be reduced.

(2) Fluoride concentrations exceeds 2 mg/L
   a. The fluoride chemical feed equipment will be shut-off
   b. Verification grab samples shall be taken at the sampling hydrant that exceeds the 2 mg/L concentration and brought to the lab for analysis.
   c. If the additional grab samples indicate concentrations are within limits (2 mg/L or less) the injection equipment may be turned back on with the consent of the project officer and the Nicholasville WTP utility staff.
   d. If grab samples indicate concentrations exceeding 2 mg/L the Kentucky Department of Environmental Protection will be contacted.

3.8 Documentation and Records

Raw data collected in the field will be recorded on paper forms (in ink) that have been especially developed for this purpose (see Appendices B and C). Once completed the forms will be scanned into an adobe pdf for subsequent electronic archival. The data will also be transcribed into an excel spreadsheet. Copies of all documents and records shall be provided to and maintained by the Data Manager. The Data Manager will review all data for consistency and compliance with all sampling QA/QC protocols prior to recording. Any apparently anomalous values will be verified with the field personnel and where present will be documented. This information will be conveyed to the Field Supervisor for possible review and revision of the current data collection protocols. Any equipment failures during the field tests shall be documented using The Field Equipment Maintenance/Failure Log (Figure. 10). Electronic data backup will be performed after each entry session on a Digital Versatile Disc (DVD) or peripheral hard drive.

A hardcopy of all project logs, forms, records, and reports shall be archived by the Data Manager. Hardcopies of all logs, forms, records, and reports shall be made available upon request and pending approval of the Data Manager.

3.9 Data Recording Forms

The quality of the collected data will be preserved by using standardized data collection forms:

C-Factor Testing Data Sheets
When C-factor tests are performed, a C-Factor Data Collection Log (See Figure 6 and 7) will be completed. Refer to Appendix B for C-factor testing procedures.

Fire Flow Testing Data Sheets
When fire flow tests are performed, a Fire Flow Data Collection Log (See Figure 8 and 9) will be completed. Refer to Appendix C for fire flow testing procedures.

Equipment Maintenance/Failure
When maintenance is performed on the equipment or if failure occurs, an Equipment Maintenance/Failure Log (See Figure 10) shall be completed. This log will serve as a corrective action report for field activities.

Corrective Action Reports
The Field Equipment Maintenance/Failure Log (Figure. 10) shall suffice as the corrective action report for field activities. The Database Correction Log (Figure. 11) shall suffice as the corrective action report for database errors. All other corrective actions shall be documented in writing and sent to project personnel.

Grab Sampling Collection Log
When grab samples are collected in the field they will be recorded on the grab sample collection log (See Figure 12).

Chain of Custody Records
The chain of custody records (See Figure 13) will help to identify the person collecting the samples as well as other who are in charge of transporting or receiving the grab samples.

Data Tracking Log
The data tracking log (See Figure 14) will be used by the laboratory at the University of Kentucky. It will contain the lab's analysis of the concentration and the date and time the analysis was performed.

C-Factor Data Collection Log

Site ID _____

Flowing Hydrant

Nicholasville Hydrant #: _____
Project Hydrant ID: _____
Hydrant Location:_____
_____
Gage Elevation: _____
Equipment ID: _____

Residual Hydrant #1

Nicholasville Hydrant #: _____
Project Hydrant ID:
Hydrant Location:_____
_____
Gage Elevation: _____
Equipment ID:

Residual Hydrant #2

Nicholasville Hydrant #: _____
Project Hydrant ID:_____
Hydrant Location:_____
_____
Gage Elevation: _____
Equipment ID:_____

Date	Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Static Pressure (psi)	Residual Pressure (psi)	Static Pressure (psi)	Residual Pressure (psi)
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							

Distance Between Residual Hydrant #1 and Residual Hydrant #2: _____
Projected Results at 20 Psi Residual: _____ gpm, or at _____ psi Residual _____ gpm

Remarks:

Figure 6 C-Factor Data Collection Log (1 of 2)

C-Factor Data Collection Log

Tank Levels (ft) **Pump Operations**

Date	Time	Stephens Drive	Lake Street	Capital Court	Pump 1 Flow (gpm)	Pump 2 Flow (gpm)	Pump 3 Flow (gpm)	Pump 4 Flow (gpm)	Pump 5 Flow (gpm)
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								

Corresponding Flow Hydrant: _____ Corresponding Residual Hydrant: _____
Consumption Rate during Test _____
Remarks:

Figure 7 C-Factor Data Collection Log (2 of 2)

Fire Flow Data Collection Log

Site ID: _____

Flowing Hydrant

Nicholasville Hydrant #: _____
Project Hydrant ID:_____
Hydrant Location:_____
_____
Gage Elevation: _____
Equipment ID: _____

Residual Hydrant

Nicholasville Hydrant #: _____
Project Hydrant ID:_____
Hydrant Location:_____
_____
Gage Elevation: _____
Equipment ID: _____

Date	Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						

Projected Results at 20 Psi Residual: _____ gpm, or at _____ psi Residual _____ gpm

Remarks:

Figure 8 Fire Flow Data Collection Log (1 of 2)

Fire Flow Data Collection Log

Site ID: _____

Tank Levels (ft) **Pump Operations**

Date	Time	Stephens Drive	Lake Street	Capital Court	Pump 1 Flow (gpm)	Pump 2 Flow (gpm)	Pump 3 Flow (gpm)	Pump 4 Flow (gpm)	Pump 5 Flow (gpm)
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								

Corresponding Flow Hydrant: _____ Corresponding Residual Hydrant: _____
Consumption Rate during Test _____
Remarks:

Figure 9 Fire Flow Data Collection Log (2 of 2)

Nicholasville Model Calibration Project

Equipment Maintenance/Failure Log

Date	Site ID	Equipment	Date and Time Maintenance/Failure Occurred

Nature of Maintenance/Failure (circle)				List Specific Part(s)
power	mechanical	electronic	other	

Describe Maintenance/Failure and Reasons for Maintenance/Failure	

Describe Impact of Maintenance/Failure on Sample Collection	

Describe Actions	

Equipment Resumed Operation	
Date	Time

Signature: _____

Figure 10 Equipment Maintenance/ Failure Log

Nicholasville Model Calibration Project

Database Correction Log

Date	Database Table	Table Field	Table Record No.	Wrong Value	Corrected Value	Person Making Correction	Comments

Figure 11 Database Correction Log

Grab Sample Collection Log

Date: _____ Technicians: _____
Signatures: _____
_____

Site ID	Time	Sample ID*	Field Concentration Measurement (mg/L)	Comments

*Sample ID consists of site ID, sample date (MMDDYY), sample time –HHMM, and sample type

Figure 12. Grab Sample Collection Log

Nicholasville Model Calibration Project

Chain of Custody Record

Sample ID	Sample ID

Person Collecting Samples: (*Signature*)	Date	Time

Relinguished by: (*Signature*)	Received by: (*Signtature*)	Date	Time
Relinguished by: (*Signature*)	Received by: (*Signtature*)	Date	Time
Relinguished by: (*Signature*)	Received by: (*Signtature*)	Date	Time
Relinguished by: (*Signature*)	Received by: (*Signtature*)	Date	Time

Samples Disposed by: (*Signature*)	Date	Time

Page 1 of _____

Figure 13. Chain-of-Custody Record

Nicholasville Model Calibration Project

Field Grab Samples

Data Tracking Log: Fluoride Samples

Site ID	Date Samples Collected	Date Samples Shipped	Date Samples Received	Date Analysis Performed	Lab Data Sheets Received by QA/QC Manager

Figure 14. Data Tracking Log

4.0 Quality Control for Field Testing Activities

4.1 C-Factor Testing Quality Control

The quality of the data collected as part of the C-factor testing will be controlled through the following steps:

4.1.1 Review of Construction Records to Identify Potentially Partially Closed Valves

Prior to conducting any C-factor tests, recent construction records shall be reviewed to identify those parts of the system where valves could have been left closed or partially closed. These valves will be checked in the field to verify that they are in the open position.

4.1.2 Pressure Gage Calibration

Prior to the use of pressure gages in the field, the gages will be calibrated against a known pressure source in the UK hydraulics laboratory. Following the field tests, the gages will again be checked against the known pressure source to confirm the gages are still within the calibration limits (i.e. + - 2 pounds per square inch (psi)).

In the event that any of the gages are found to be out of calibration, then the associated error in each gage will be determined and the error information recorded on the data logging sheets for any tests in which the gage was used.

4.1.3 Pressure Gage Validation

Following calibration in the laboratory, each gage will be further tested against a field pressure source to confirm the gages are within the specified calibration limit. The field source could either be a tap on the downstream side of the pump discharge at the Nicholasville water treatment plant or at the base of one of the water tanks with known water surface elevation.

4.1.4 Pressure Snubbers

All pressure gages shall be used with a pressure snubber (see Figure F.5 in Appendix F) so as to decrease the fluctuations on the gage due to transients associated with the flow of water through the discharge hydrant. When reading the pressures from the gage, the observer should attempt to determine the mean value of any remaining pressure fluctuations so as to minimize any associated reading error.

4.1.5 Duplicate Pressure Observations

All pressure gage readings should be performed independently by two separate observers. These readings should be confirmed prior to recording a single value. In the event the observed values remain consistently apart, the mean of the readings should be recorded.

In performing any C-factor tests, two pressure gages will be used. Prior to flowing the discharge hydrant, the static pressures at each of the residual hydrants should be measured and recorded. In order to minimize any potential gage error, the static pressures at each hydrant should be measured twice, with the gages switched between measurements. The observed pressures should remain consistent within the specified pressure tolerance (i.e. + - 2 psi). In the event the gage readings are not consistent then the difference should be noted on the data collection form prior to their use. This test should be performed during the first test and the last test of the day to confirm that the gages have not lost their calibration over the course of the tests.

After the static differences have been confirmed, the C-factor test should be performed twice, with the gages switched between tests. The observed pressures should remain consistent within the specified pressure tolerance (i.e. + - 2 psi). In the event the gage readings are not consistent then the difference should be noted on the data collection form prior to their use. This test should be performed during the first test and the last test of the day to confirm that the gages have not lost their calibration over the course of the tests.

4.1.6 Adequate Hydrant Discharge for C-Factor Test

In order to insure that sufficient headloss is generated during the C-Factor test to allow the accurate calculation of the C-factor, the pressure drop between the two residual hydrants should be at least 15 psi. If such a pressure drop is not obtained, it will be necessary to open additional hydrants so as to generate a sufficient pressure drop. If a low pressure drop is associated with an un-expectantly low discharge from the hydrant it is possible that there is a closed or partially closed valve upstream of the test area. If this occurs, the upstream valves should be re-checked to make sure that they are opened prior to repeating the test.

4.2 Fire Flow Testing Quality Control

In conducting a fire flow test for the purpose of hydraulic model calibration, a minimum of two hydrants are employed (see Appendix A for details). One hydrant (flow hydrant) is used to discharge flows to the environment while another upstream hydrant (residual hydrant) is used to measure the pressure drop.

4.2.1 Adequate Hydrant Discharge for Fire Flow Tests

The magnitude of the discharge from the hydrant should be sufficient to insure a pressure drop in the residual hydrant of at least 15 psi. In the event that such a drop cannot be achieved, then a second downstream hydrant may need to be flowed simultaneously with the first one. In this case, both discharge hydrants will need to be instrumented with flow/ pressure meters. If a low pressure drop is associated with an un-expectantly low discharge from the hydrant it is possible that there is a closed or partially closed valve upstream of the test area. If this occurs, the upstream valves should be re-checked to make sure that they are opened prior to repeating the test.

4.2.2 Discharge Measurement

Most hydrant flow/pressure gages come with two scales, one for discharge and one for pressure. The discharge scale is only applicable for certain types of hydrant nozzles. As a result, the discharge scale should not be used. Instead, the discharge pressure should be measured and then converted into discharge using the following equation:

For discharge volume

$$GPM = 29.84 * C * D^2 * \sqrt{P}$$

Where:
C = coefficient of discharge*
D= the diameter of hydrant opening (in)
P= discharge/pitot pressure (psi)
**This information is recorded for each hydrant in the Nicholasville Hydrant Report usually .9*

In some cases, the accuracy of the results cannot be determined on site due to the time needed to input the collected data into KYPIPE. Once the data are entered into KYPIPE, there may be additional errors with the data that were not readily identified in the field. An example would be if the computer model produced a low Hazen Williams coefficient such as 40 or below. This would indicate that there may be a valve closed in the system or that the C-Factor test data were in error. These errors will be reviewed by the Principal Investigator and a course of action will be determined based upon the complexity of the situation.

4.2.3 Fire Flow Test Validation

The City of Nicholasville has run fire-flow tests on many of their existing hydrants. In the event that one of the hydrants used in this study corresponds to one of these hydrants, the previous fire flow results for that hydrant should be obtained and compared with the results from the new fire flow test. Prior testing information usually contains the available fire flow at a 20 psi residual. The procedure for calculating the available flow at a 20 psi residual is located in Appendix C. In the event that these results are significantly different (e.g. significantly lower), the field crew should check to insure that there are no closed or partially closed valves upstream of the test area. In the event that such errors are determined, then the fire-flow tests will need to be re-run. In the event that no such valves can be located, the field team should note the discrepancy and attempt to develop a hypothesis for the difference.

While every attempt should be made to insure that the system geometry of the computer model is correct and that there are no closed or partially closed valves upstream of the test area, such errors may not be readily apparent until after the collected data are entered into the computer and the model used to predict the observed pressures and flows. When such an analysis requires a roughness coefficient excessively lower than those observed during the C-factor test, the most likely reason is due to errors in the system geometry or the existence of closed or partially closed valves. Guidance for identifying and correcting such macro-level calibration errors is provided in Appendix A. In the event that such errors are determined, then the fire-flow tests will need to be re-run. Any C-factor tests will not be affected unless the partially closed valve is determined to be in the segment of pipe that was used in the C-factor test.

4.3 Tracer Study Quality Control

Quality control techniques for data collection will include collecting duplicate grab samples. The hydrants will need to be flowed at a designated rate in order to obtain a good representative sample. Appendix H outlines guidelines and procedures for collecting a good representative sample. These guidelines were created by the US EPA technical support center and will be used to ensure when performing grab sampling in the field. At each hydrant, two grab samples will periodically be collected for a particular time interval. This will allow us two compare each sample to ensure that there is consistency of each test and help account for errors when collecting each sample. Once samples are collected they will be placed in coolers with ice to prevent the concentration from being affected by temperatures in the environment.

For field testing purposes, quality control will consist of calibrating the equipment (Hach Colorimeter) prior to performing the tracer test. It will be calibrated against a known solution of fluoride (1 mg/L). During actual field testing, the Hach Colorimeter will be recalibrated every 10-15 samples to ensure the calibration equipment is performing accurately and to help check for bias that could arise from testing procedure or instrument

inaccuracies. Grab samples will occasionally be tested twice, once in the field with the Hach Colorimeter and again in the KGS laboratory. Lab testing of grab samples will also conduct its own procedure for quality assurance consistent with SW846-9056 method. SW846-9056 quality control is as follows:

A quality control sample obtained from an outside source must first be used for the initial verification of the calibration standards. A fresh portion of this sample should be analyzed every week to monitor stability. If the results are not within +/- 10 % of the true value listed for the control sample, prepare a new calibration standard and recalibrate the instrument. If this does not correct the problem, prepare a new standard and repeat the calibration. A quality control sample should be run at the beginning and end of each sample delivery group (SDG) or at the frequency of one per every ten samples. The QC's value should fall between ± 10 % of its theoretical concentration.

A duplicate should be run for each SDG or at the frequency of one per every twenty samples, whichever is greater. The RPD (Relative Percent Difference) should be less than 10%. If this difference is exceeded, the duplicate must be reanalyzed.

From each pair of duplicate analytes (X_1 and X_2), calculate their RPD value:

$$\%PRD = 2 * \left(\frac{X_1 - X_2}{X_1 + X_2}\right) * 100$$

(X_1 - X_2) means the absolute difference between X_1 and X_2.

5.0 Summary

The University of Kentucky needs to develop a calibrated hydraulic and water quality model as a part of a larger research project for the Department of Hometown Security. The calibrated hydraulic and water quality model will assist with the development of an improved understanding about the impact of flow dynamics changes on distribution system water quality, and the potential benefits of using real-time network models to improve operational decisions – including detection and response to potential contamination events. Hydraulic model calibration will consist of a fire flow test, and C-factor tests. Water quality model calibration will consist of performing a tracer study. This QAPP describes the general procedures, hydrant testing methods, and the equipment that will be used to obtain hydraulic data.

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Appendix A: Water Distribution System Model Calibration

A.1 Introduction

Computer models for analyzing and designing water distribution systems have been available since the mid 1960's. Since then, however, many advances have been made with regard to the sophistication and application of this technology. A primary reason for the growth and use of computer models has been the availability and widespread use of the microcomputer. With the advent of this technology it has been possible for water utilities and engineers to analyze the status and operations of the existing system as well as to investigate the impacts of proposed changes (Ormsbee and Chase, 1988). The validity of these models, however, depends largely on the accuracy of the input data.

A.1.1 Network Characterization

Before an actual water distribution system may be modeled or simulated with a computer program, the physical system must be represented in a form that can be analyzed by a computer. This will normally require that the water distribution system first be represented by using node-link characterization (see Figure A.1). In this case the links represent individual pipe sections and the nodes represent points in the system where two or more pipes (links) join together or where water is being input or withdrawn from the system.

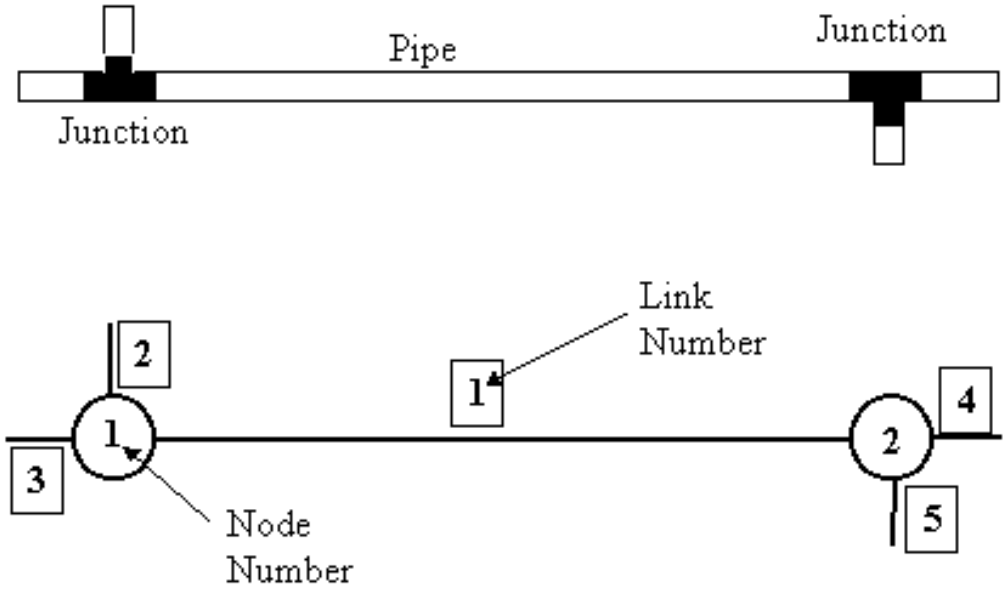

Figure A.1. Node-Link Characterization

A.1.2 Network Data Requirements

Data associated with each link will include a pipe identification number, pipe length, pipe diameter, and pipe roughness. Data associated with each junction node will include a junction identification number, junction elevation, and junction demand. Although it is recognized that water leaves the system in a time varying fashion through various service connections along the length of a pipe segment, it is generally acceptable in modeling to lump half of the demands along a line to the upstream node and the other half of the demands to the downstream node as shown in Figure A.2.

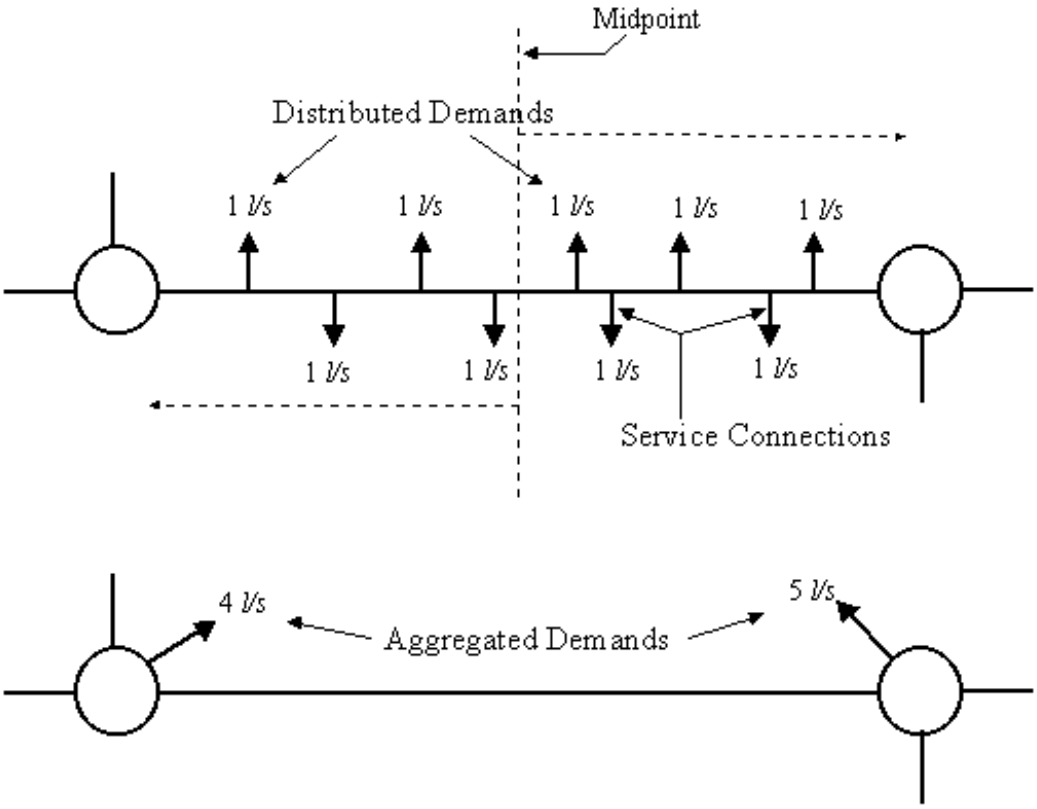

Figure A.2. Demand Load Simplification

In addition to the network pipe and node data, physical data for use in describing all tanks, reservoirs, pumps, and valves must also be obtained. Physical data for all tanks and reservoirs will normally include information on tank geometry as well as the initial water levels. Physical data for all pumps will normally include either the value of the average useful horsepower, or data for use in describing the pump flow/head characteristics curve. Once this necessary data for the network model has been obtained, the data should be entered into the computer in a format compatible with the selected computer model.

A.1.3 Model Parameters

Once the data for the computer network model has been assembled and encoded, the associated model parameters should then be determined prior to actual model application. In general, the primary parameters associated with a hydraulic network model will include pipe roughness and nodal demands. Due to the difficulty of obtaining economic and reliable measurements of both parameters, final model values are normally determined through the process of model calibration. Model calibration involves the adjustment of the primary network model parameters (i.e. pipe roughness coefficients and nodal demands) until the model results closely approximate actual observed conditions as measured from field data. In general, a network model calibration effort should encompass seven basic steps (see Figure A.3). Each of these steps is discussed in detail in the following sections.

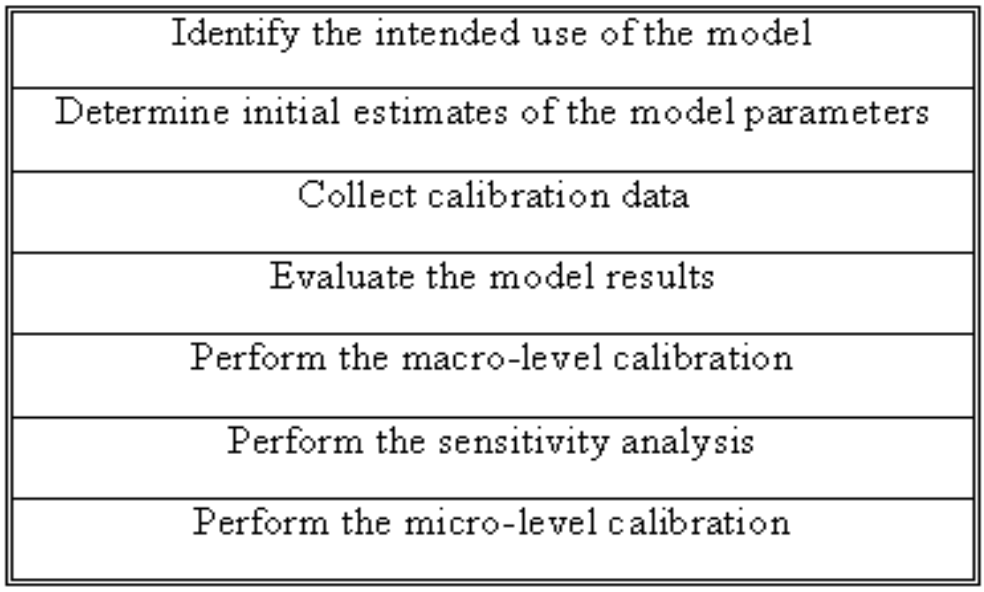
Identify the intended use of the model
Determine initial estimates of the model parameters
Collect calibration data
Evaluate the model results
Perform the macro-level calibration
Perform the sensitivity analysis
Perform the micro-level calibration

Figure A.3. Seven Basic Steps for Network Model Calibration

2 Identify the Intended Use of the Model

Before calibrating a hydraulic network model, it is important to first identify its intended use (e.g., pipe sizing for master planning, operational studies, design projects, rehabilitation studies, water quality studies) and the associated type of hydraulic analysis (steady-state versus extended-period). Usually the type of analysis is directly related to the intended use. For example, water quality and operational studies require an extended-period analysis, whereas some planning or design studies may be performed using a study state analysis (Walski, 1995). In the latter, the model predicts system pressures and flows

at an instant in time under a specific set of operating conditions and demands (e.g., average or maximum daily demands). This is analogous to photographing the system at a specific point in time. In extended-period analysis, the model predicts system pressures and flows over an extended period (typically 24 hours). This is analogous to developing a movie of the system performance.

Both the intended use of the model and the associated type of analysis provide some guidance about the type and quality of collected field data and the desired level of agreement between observed and predicted flows and pressures (Walski, 1995). Models for steady-state applications can be calibrated using multiple static flow and pressure observations collected at different times of day under varying operating conditions. On the other hand, models for extended-period applications require field data collected over an extended period (e.g., one to seven days).

In general, a higher level of model calibration is required for water quality analysis or an operational study than for a general planning study. For example, determining ground evaluations using a topographic map may be adequate for one type of study, whereas another type of study may require an actual field survey. This may depend on the contour interval of the map used. Such considerations obviously influence the methods used to collect the necessary model data and the subsequent calibration steps. For example, if one is working in a fairly steep terrain (e.g. greater than 20 foot contour intervals), one may decide to use a GPS unit for determining key elevations other than simply interpolating between contours.

A.3 Determining Model Parameter Estimates

The second step in calibrating a hydraulic network model is to determine initial estimates of the primary model parameters. Although most models will have some degree of uncertainty associated with several model parameters, the two model parameters that normally have the greatest degree of uncertainty are the pipe roughness coefficients and the demands to be assigned to each junction node.

A.3.1 Pipe Roughness Values

Initial estimates of pipe roughness values may be obtained using average literature values or directly from field measurements. Various researchers and pipe manufacturers have developed tables that provide estimates of pipe roughness as a function of various pipe characteristics such as pipe material, pipe diameter, and pipe age (Lamont, 1981). One such typical table is shown in Table A.1 (Wood, 1991). Although such tables may be useful for new pipes, their specific applicability to older pipes decreases significantly as the pipes age. This may result due to the affects of such things as tuberculation, water

chemistry, etc. As a result, initial estimates of pipe roughness for all pipes other than relatively new pipes should normally come directly from field testing. Even when new pipes are being used it is helpful to verify the roughness values in the field since the roughness coefficient used in the model may actually represent a composite of several secondary factors such as fitting losses and system skeletonization.

Table A.1. Typical Hazen-William Pipe Roughness Factors

Pipe Material	Age (years)	Diameter	C Factor
Cast Iron	New	All Sizes	130
	5	>380mm (15in)	120
		>100mm (4in)	118
	10	>600mm (24in)	113
		>300mm (12in)	111
		>100mm (4in)	107
	20	>600mm (24in)	100
		>300mm (12in)	96
		>100mm (4in)	89
	30	>760mm (30in)	90
		>400mm (16in)	87
		>100mm (4in)	75
	40	>760mm (30in)	83
		>400mm (16in)	80
		>100mm (4in)	64
Ductile Iron	New		140
Plastic PVC	Average		140
Asbestos Cement	Average		140
Wood Stave	Average		120

A.3.1.1 Pipe Roughness Chart

A customized roughness nomograph for a particular water distribution system may be developed using the process illustrated in Figure A.4. To obtain initial estimates of pipe roughness through field testing, it is best to divide the water distribution system into homogeneous zones based on the age and material of the associated pipes (see Figure A.4a). Next, several pipes of different diameters should be tested in each zone to obtain individual pipe roughness estimates (see Figure A.4b). Once a customized roughness nomograph is constructed, (see Figure A.4c), it can be used to assign values of pipe roughness for the rest of the pipes in the system.

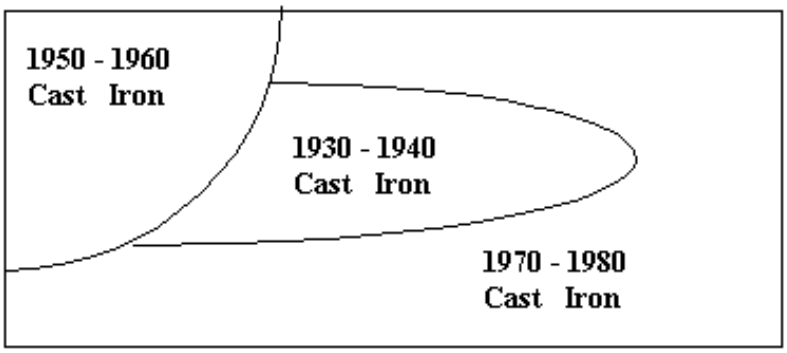

Figure A.4a. Subdivide Network into Homogeneous Zones of Like Age and Material

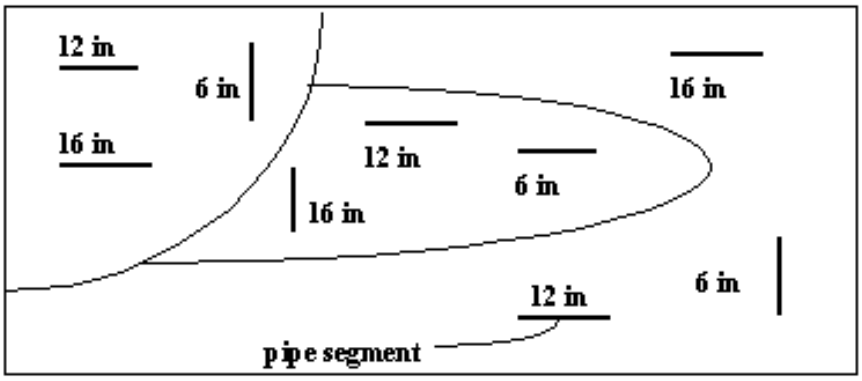

Figure A.4b. Selected Representative Pipes from Each Zone

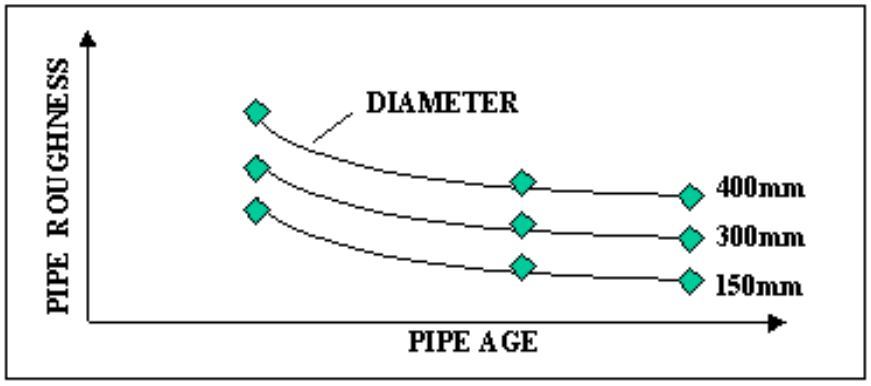

Figure A.4c. Plot Associated Roughness as a Function of Pipe Diameter and Age

A.3.1.2 Pipe Roughness Field Estimation

Pipe roughness values may be estimated in the field by selecting a straight section of pipe that contains a minimum of three fire hydrants (see Figure A.5a). When the line has been selected, pipe roughness may be estimated using one of two methods (Walski, 1984): 1) The parallel-pipe method (see Figure A.5b) or 2) The two-hydrant method (see Figure A.5c). In each method, the length and diameter of the test pipe are first determined. Next, the test pipe is isolated, and the flow and pressure drop are measured either through the use of a differential pressure gauge or by using two separate pressure gauges. Pipe roughness can then be approximated by a direct application of either the Hazen-Williams equation or the Darcy-Weisbach equation. In general, the parallel-pipe method is preferable for short runs and for determining minor losses around valves and fittings. For long runs of pipe, the two-gage method is generally preferred. Also, if the water in the parallel pipe heats up or if a small leak occurs in the parallel line, it can lead to errors in the associated head loss measurements (Walski, 1985).

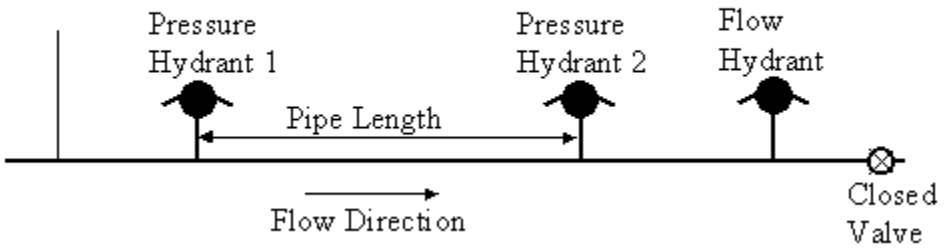

Figure A.5a. Pipe Roughness Test Configuration

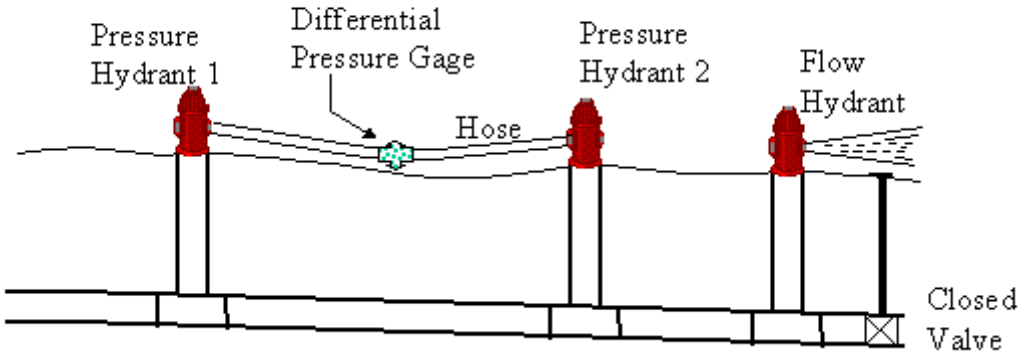

Figure A.5b. Parallel Pipe Method

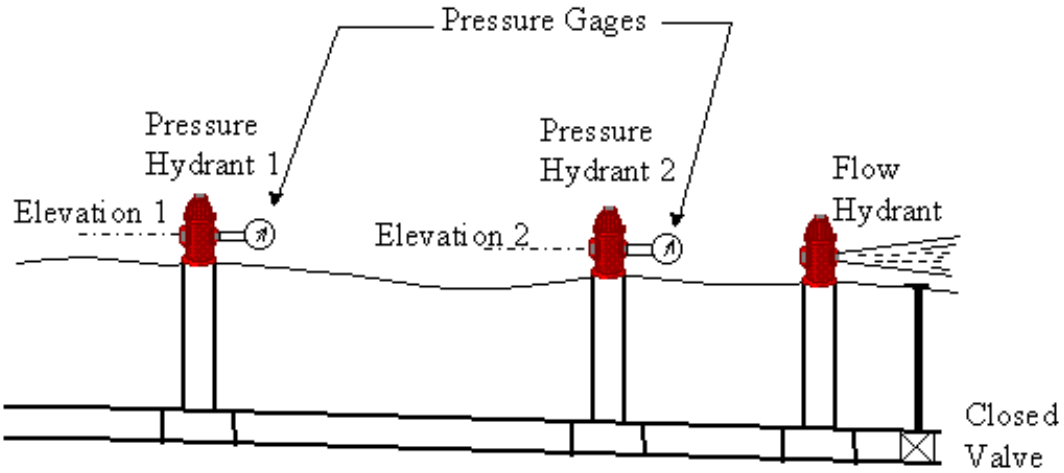

Figure A.5c. Two Gage Method

A.3.1.2.1 The Parallel-Pipe Method

The steps involved in the application of the parallel pipe method are summarized as follows:

1) Measure the length of pipe between the two upstream hydrants (Lp) in meters.

2) Determine the diameter of the pipe (Dp) in mm. In general this should simply be the nominal diameter of the pipe. It is recognized that the actual diameter may differ from this diameter due to variations in wall thickness or the buildup of tuberculation in the pipe. However, the normal calibration practice is to incorporate the influences of variations in pipe diameter via the roughness coefficient. It should be recognized however, that although such an approach should not significantly influence the distribution of flow or headloss throughout the system it may have a significant influence on pipe velocity, which in turn could influence the results of a water quality analysis.

3) Connect the two upstream hydrants with a pair of parallel pipes, (typically a pair of fire hoses) with a differential pressure device located in between (see Figure A.5b). The differential pressure device can be a differential pressure gage, an electronic transducer or a manometer. Walski (1984) recommends the use of an air filled manometer due to its simplicity, reliability, durability and low cost. (Note: When connecting the two hoses to the differential pressure device, make certain that there is no flow through the hoses. If there is any leak in the hoses the computed headloss for the pipe will be in error by an amount equal to the headloss through the hose).

4) Open both hydrants and check all connections to insure there are no leaks in the configuration.

5) Close the valve downstream of the last hydrant and then open the smaller nozzle on the flow hydrant to generate a constant flow through the isolated section of pipe. Make sure the discharge has reached equilibrium condition before taking flow and pressure measurements.

6) Determine the discharge Qp (l/s) from the smaller nozzle in the downstream hydrant. This is normally accomplished by measuring the discharge pressure Pd of the stream leaving the hydrant nozzle using either a hand held or nozzle mounted pitot. Once the discharge pressure Pd (in kPa) is determined it can be converted to discharge (Qp) using following relationship:

$$Q_p = C_d D_n^2 P_d^{0.5} / 900.3$$

..... eq. A.1

where Dn is the nozzle diameter in mm and Cd is the nozzle discharge coefficient which is a function of the type of nozzle (see Figure 6). (Note: When working with larger mains, sometimes you can't get enough water out of the smaller nozzles to get a good pressure drop. In such cases you may need to use the larger nozzle).

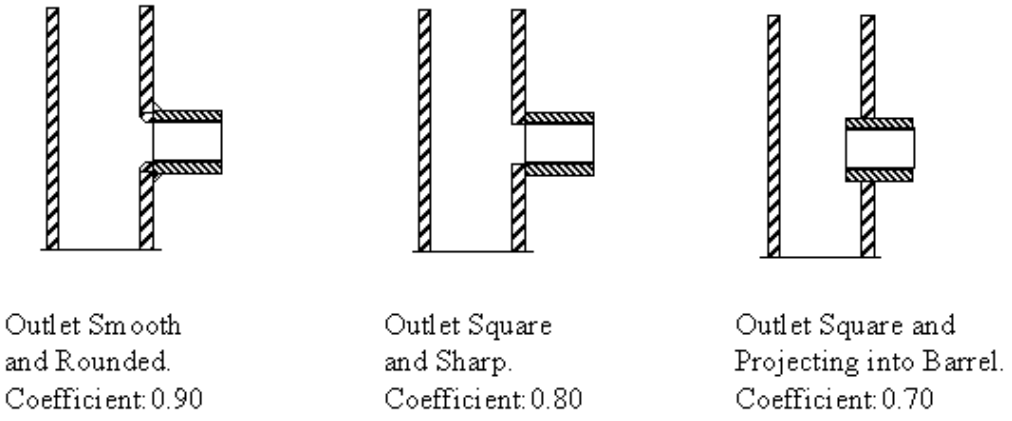
Outlet Smooth and Rounded. Coefficient: 0.90
Outlet Square and Sharp. Coefficient: 0.80
Outlet Square and Projecting into Barrel. Coefficient: 0.70

Figure A.6. Hydrant Nozzle Discharge Coefficients

7) After calculating the discharge, determine the in-line flow velocity Vp (m/s) where:

$$V_p = Q_p / (\pi D_p^2 / 4)^2$$

..... eq. A.2

8) After the flow through the hydrant has been determined, measure the pressure drop (p) through the isolated section of pipe by reading the differential pressure gage.

Convert the measured pressure drop in units of meters (Hp) and divided by the pipe length Lp to yield the hydraulic gradient or friction slope Sp.

$$S_p = H_p / L_p$$

..... eq. A.3

9a) Once these four measured quantities have been obtained, the Hazen-Williams Roughness Factor (Cp) can then be determined using the Hazen-Williams equation as follows:

$$C_p = \frac{218 V_p}{D_p^{0.63} S_p^{0.54}}$$

..... eq. A.4

9b) To calculate the actual pipe roughness , it is first necessary to calculate the friction factor f using the Darcy-Weisbach equation as follows (Walski, 1984):

$$f = \frac{g S_p D_p}{500 V_p^2}$$

..... eq. A.5

where g = gravitational acceleration constant (9.81m/sec2)

Once the friction factor has been calculated, the Reynolds number must be determined. Assuming a standard water temperature of 20ºC (68º F), the Reynolds number is:

$$R = 993 V_p D_p$$

..... eq. A.6

Once the friction factor f, and the Reynolds number R have been determined, they can be inserted into the Colebrook-White formula to give the pipe roughness E (mm) as:

$$\varepsilon = 3.7 D_p \left\{ \exp(-1.16\sqrt{f}) - 2.51 / R\sqrt{f} \right\}$$

..... eq. A.7

A.3.1.2.2. The Two-hydrant Method

The two hydrant method is basically identical to the parallel pipe method with the exception that the pressure drop across the pipe is measured using a pair of static pressure gages as shown in Figure A.5c. In this case the total headloss through the pipe is the

difference between the hydraulic grades at both hydrants. In order to obtain the hydraulic grade at each hydrant, the observed pressure head (m) must be added to the elevation of the reference point (the hydrant nozzle). For the two hydrant method, the head loss through the test section Hp (m) can be calculated using the following equation:

$$H_p = {}^{(P_2 - P_1)}\!/_{9.81} + (Z_2 - Z_1)$$

..... eq. A.8

where P1 is the pressure reading at the upstream gage (kPa) , Z1 is the elevation of the upstream gage (m), P2 is the pressure reading at the downstream gage (kPa), and Z2 is the elevation of the downstream gage (m).

The elevation difference between the two gages should generally be determined using a transit or a level. As a result, one should make sure to select two upstream hydrants that can be seen from a common point. This will minimize the number of turning points required in determining the elevation differences between the nozzles of the two hydrants. As an alternative to the use of a differential survey, topographic maps can sometimes be used to obtain estimates of hydrant elevations. However, topographic maps should not generally be used to estimate the elevation differences unless the contour interval is 1m or less. One hydraulic alternative to measuring the elevations directly is to simply measure the static pressure readings at both hydrants before the test and convert the observed pressure difference to the associated elevation difference (e.g. Z1 - Z2 = 2.31*[P2(static) - P1(static)]).

A.3.1.2.3. General Observations and Suggestions

Hydrant pressures for use in pipe roughness tests are normally measured with a Bourdon tube gage which can be mounted to one of the discharge nozzles of the hydrant using a lightweight hydrant cap. Bourdon tube gages come in various grades (i.e 2A, A, and B) depending upon their relative measurement error. In most cases a grade A gage (1 percent error) is sufficient for fire flow tests. For maximum accuracy one should chose a gage graded in 5kPa (1 psi) increments with a maximum reading less than 20% above the expected maximum pressure (McEnroe, et al., 1989). In addition, it is a good idea to use pressure snubbers in order to eliminate the transient effects in the pressure gages. A pressure snubber is a small valve that is placed between the pressure gage and the hydrant cap which acts as a surge inhibitor (Walski, 1984).

Before conducting a pipe roughness test, it is always a good idea to make a visual survey of the test area. When surveying the area, make sure that there is adequate drainage away from the flow hydrant. In addition, make sure you select a hydrant nozzle that will not discharge into oncoming traffic. Also, when working with hydrants that are in close proximity to traffic, it is a good idea to put up traffic signs and use traffic cones to

provide a measure of safety during the test. As a further safety precaution, make sure all personnel are wearing highly visible clothing. It is also a good idea to equip testing personnel with radios or walkie-talkies to help coordinate the test.

While the methods outlined previously work fairly well with smaller lines (i.e. less than 16in in diameter), their efficiency decreases as you deal with larger lines. Normally, opening hydrants just doesn't generate enough flow for meaningful head-loss determination. For such larger lines you typically have to conduct the headloss tests over very much longer runs of pipe and use either plant or pump station flow meters or change in tank level to determine flow (Walski, 1999).

A.3.2 Nodal Demand Distribution

The second major parameter determined in calibration analysis is the average (steady-state analysis) or temporally varying (extended-period analysis) demand to be assigned to each junction node. Initial average estimates of nodal demands can be obtained by identifying a region of influence associated with each junction node, identifying the types of demand units in the service area, and multiplying the number of each type by an associated demand factor. Alternatively, the estimate can be obtained by first identifying the area associated with each type of land use in the service area and then multiplying the area of each type by an associated demand factor. In either case, the sum of these products will provide an estimate of the demand at the junction node.

A.3.2.1 Spatial Distribution of Demands

Initial estimates of nodal demands can be developed using various approaches depending on the nature of the data each utility has on file and how precise they want to be. One way to determine such demands is by employing the following strategy.

1. First, determine the total system demand for the day to be used in model calibration (i.e. TD). The total system demand may be obtained by performing a mass balance analysis for the system by determining the net difference between the total volume of flow which enters the system (from both pumping stations and tanks) and the total volume that leaves the system (through PRVs and tanks).

2. Second, using meter records for the day, try to assign all major metered demands (i.e. MDj where j = junction node number) by distributing the observed demands among the various junction nodes which serve the metered area. The remaining demand will be defined as the total residual demand (i.e. TRD) and may be obtained by subtracting the sum of the metered demands from the total system demand:

$$TRD = TD - \sum MD_j$$

..... eq. A.9

3. Third, determine the demand service area associated with each junction node. The most common method of influence delineation is to simply bisect each pipe connected to the reference node.

4. Once the service areas associated with the remaining junction nodes have been determined, an initial estimate of the demand at each node should be made. This can be accomplished by first identifying the number of different types of demand units within the service area and then multiplying the number of each type by an associated demand factor. Alternatively, the estimate can be obtained by first identifying the area associated with each different type of land use within the service area and then multiplying the area of each type by an associated unit area demand factor. In either case, the sum of these products will represent an estimate of the demand at the junction node. While in theory the first approach should be more accurate the later approach can be expected to be more expedient. Estimates of unit demand factors are normally available from various water resource handbooks (Cesario, 1995). Estimates of unit area demand factors can normally be constructed for different land use categories by weighted results from repeated applications of the unit demand approach.

5. Once an initial estimate of the demand has been obtained for each junction node j (i.e. IEDj), a revised estimated demand (i.e. REDj) may be obtained using the following equation:

$$RED_j = IED_j * TRD / \quad IED_i$$

..... eq. A.10

6. Once the revised demands have been obtained for each junction node, the final estimate of nodal demand can be obtained by adding together both the revised demand and the metered demand (assuming there is one) associated with each junction node:

$$D_j = NED_j + MD_j$$

..... eq. A.11

A.3.2.2 Temporal Distribution of Demands

Time-varying estimates of model demands for use in extended-period analysis can be made in one of two ways, depending on the structure of the hydraulic model. Some models allow the user to sub-divide the demands at each junction node into different use categories, which can then be modified separately over time using demand factors for water use categories. Other models require an aggregate-use category for each node. In the latter case, spatial-temporal variations of nodal demands are obtained by lumping nodes of a given type into separate groups, which can then be modified uniformly using nodal demand factors. Initial estimates of either water use category demand factors or nodal demand factors can be obtained by examining historical meter records for various water use categories and by performing incremental mass balance calculations for the

distribution system. The resulting set of temporal demand factors can then be fine tuned through subsequent model calibration.

A.4 Collect Calibration Data

After model parameters have been estimated, the accuracy of the model parameters can be assessed. This is done by executing the computer model using the estimated parameter values and observed boundary conditions and then comparing the model results with the results from actual field observations. Data from fire flow tests, pump station flowmeter readings, and tank telemetry data are most commonly used in such tests.

In collecting data for model calibration, it is very important to recognize the significant impact of measurement errors. For example, with regard to calibrating pipe roughness, the C factor may be expressed as:

$$C = k(V + \text{error})/(h + \text{error})^{0.54}$$

..... eq. A.12

If the magnitude of V and h are on the same order of magnitude as the associated measurement errors (for V and h) then the collected data will be essentially useless for model calibration. That is to say, virtually any value of C will provide a "reasonable" degree of model calibration (Walski, 1986). However, one can hardly expect a model to accurately predict flows and pressures for a high stress situation (i.e. large flows and velocities) if the model was calibrated using data from times when the velocities in the pipes were less than the measurement error (e.g. less than 1 ft/s). The only way to minimize this problem is to either insure that the measurement errors are reduced or the velocity or headloss values are significantly greater than the associated measurement error. This latter condition can normally be met either using data from fire flow tests or by collecting flow or pressure readings during periods of high stress (e.g. peak hour demand periods).

A.4.1 Fire Flow Tests

Fire flow tests are useful for collecting both discharge and pressure data for use in calibrating hydraulic network models. Such tests are normally conducted using both a normal pressure gage (for measuring both static and dynamic heads) and a pitot gage (for use in calculating discharge). In performing a fire flow test, at least two separate hydrants are first selected for use in the data collection effort. One hydrant is identified as the pressure or residual hydrant while the remaining hydrant is identified as the flow hydrant. The general steps for performing a fire flow test may be summarized as follows (McEnroe, et al., 1989):

1. Place a pressure gage on the residual hydrant and measure the static pressure.

2. Determine which of the discharge hydrant's outlets can be flowed with the least amount of adverse impact (flooding, traffic disruption, etc.)

3. Make sure the discharge hydrant is initially closed in order to avoid injury.

4. Remove the hydrant cap from the nozzle of the discharge hydrant to be flowed.

5. Measure the inside diameter of the nozzle and determine the type of nozzle (i.e. rounded, square edge, or protruding) in order to determine the appropriate discharge coefficient. (see Figure A.6).

6. Take the necessary steps to minimize erosion or traffic impacts during the test.

7. Flow the hydrant briefly to flush sediment from the hydrant lateral and barrel.

8a. If using a clamp on pitot tube, attach the tube to the nozzle to be flowed and then slowly open the hydrant.

8b. If using a hand held pitot tube, slowly open the hydrant and then place the pitot in the center of the discharge stream being careful to align it directly into the flow.

9. Once an equilibrium flow condition has been established, make simultaneous pressure readings from both the pitot and the pressure gage at the residual hydrant.

10. Once the readings are completed, close the discharge hydrant, remove the equipment from both hydrants and replace the hydrant caps.

In order to obtain sufficient data for an adequate model calibration it is important that data from several fire flow tests be collected. Before conducting each test, it is also important that the associated system boundary condition data be collected. This includes information on tank levels, pump status, etc. In order to obtain adequate model calibration it is normally desirable that the difference between the static and dynamic pressure readings as measured from the residual hydrant be at least 35kPa (5psi) with a preferable drop of 140kpa (20psi) (Walski, 1990a). In the event that the discharge hydrant does not allow sufficient discharge to cause such a drop it may be necessary to identify, instrument, and open additional discharge hydrants. In some instances, it may also be beneficial to use more than one residual hydrant (one near the flowed hydrant and one off the major main from the source). The information gathered from such additional hydrants can sometimes be very useful in tracking down closed valves (Walski, 1999).

A.4.2. Telemetry Data

In addition to static test data, data collected over an extended period of time (typically 24 hours) can be very useful for use in calibrating network models. The most common type of data will include flowrate data, tank water level data, and pressure data. Depending upon the level of instrumentation and telemetry associated with the system, much of the data may be already collected as part of the normal operations. For example, most

systems collect and record tank levels and average pump station discharges on an hourly basis. These data are especially useful verifying the distribution of demands among the various junction nodes. If such data are available, the data should first be checked for accuracy before use in the calibration effort. If such data are not readily available, the modeler may have to install temporary pressure gages or flowmeters in order to obtain the data. In the absence of flowmeters in lines to tanks, inflow or discharge flow rates can be inferred from incremental readings of the tank level.

A.4.3 Water Quality Data

In recent years, both conservative and non-conservative constituents have been used as tracers to determine the travel time through various parts of a water distribution system (Grayman, 1998, Cesario, A. L., et al., 1996, Kennedy, et. al., 1991). The most common type of tracer for such applications is fluoride. By controlling the injection rate at a source, typically the water treatment plant, a pulse can be induced into the flow that can then be monitored elsewhere in the system. The relative travel time from the source to the sampling point can be determined. The measured travel time thus provides another data point for use in calibrating a hydraulic network model.

Alternatively, the water distribution system can also be modeled using a water quality model such as EPANET (Rosman, 1994). In this case the water quality model is used to predict tracer concentrations at various points in the system. Since all water quality models results depend on the underlying hydraulic results, deviations between the observed and predicted concentrations can thus provide a secondary means of evaluating the adequacy of the underlying hydraulic model.

A.5 Evaluate Model Results

In using fire flow data, the model is used to simulate the discharge from one or more fire hydrants by assigning the observed hydrant flows as nodal demands within the model. The flows and pressures predicted by the model are then compared with the corresponding observed values in an attempt to assess model accuracy. In using telemetry data, the model is used to simulate the variation of tank water levels and system pressures by simulating the operating conditions for the day over which the field data was collected. The predicted tank water levels are then compared with the observed values in an attempt to assess model accuracy. In using water quality data, the travel times (or constituent concentrations) are compared with model predictions in an attempt to assess model accuracy.

Model accuracy may be evaluated using various criteria. The most common criteria are absolute pressure difference (normally measured in psi) or relative pressure difference (measured as the ratio of the absolute pressure difference to the average pressure

difference across the system). In most cases a relative pressure difference criteria is normally to be preferred. For extended period simulations, comparisons are normally made between the predicted and observed tank water levels. To a certain extent, the desired level of model calibration will be related to the intended use of the model. For example, a higher level of model calibration will normally be required for water quality analysis or an operational study as opposed to use of the model in a general planning study. Ultimately, the model should be calibrated to the extent that the associated application decisions will not be significantly affected. In the context of a design application, the model should normally be calibrated to such an extent that the resulting design values (e.g. pipe diameters, tank and pump sizes and/or locations, etc) will be the same as if the exact parameter values were used. Determination of such thresholds will frequently require the application of model sensitivity analysis (Walski, 1995).

Because of the issue of model application, it is difficult to derive a single set of criteria for a universal model calibration. From the authors' perspective, a maximum state variable (i.e. pressure grade, water level, flowrate) deviation of less than 10 percent will generally be satisfactory for most planning applications while a maximum deviation of less than 5 percent to be highly desirable for most design, operation, or water quality applications. Although no such general set of criteria have been officially developed for the United States, a set of "Performance Criteria" have been developed by the Sewers and Water Mains Committee of the Water Authorities in the United Kingdom (1989). For steady state models the criteria are:

1. Flows agree to:
    a. 5% of measured flow when flows are more than 10% of total demand.
    b. 10% of measured flow when flows are less than 10% of total demand.
2. Pressures agree to:
    a. 0.5 m (1.6ft) or 5% of headloss for 85% of test measurements.
    b. 0.75 m (2.31 ft) or 7.5% of headloss for 95% of test measurements.
    c. 2 m (6.2 ft) or 15% of headloss for 100% of test measurements.

For extended period simulation, the criteria require that three separate steady state calibrations be performed for different time periods and that the average volumetric difference between measured and predicted reservoir storage be within 5%. Additional details can be obtained directly from the report.

Deviations between results of the model application and the field observations may be caused by several factors, including: 1) erroneous model parameters (i.e. pipe roughness values and nodal demand distribution), 2) erroneous network data (i.e. pipe diameters,

lengths, etc), 3) incorrect network geometry (i.e. pipes connected to the wrong nodes, etc.), 4) incorrect pressure zone boundary definitions, 5) errors in boundary conditions (i.e. incorrect PRV value settings, tank water levels, pump curves, etc.), 6) errors in historical operating records (i.e. pumps starting and stopping at incorrect times), 7) measurement equipment errors (i.e. pressure gages not properly calibrated, etc.), and 8) measurement error (i.e. reading the wrong values from measurement instruments). The last two sources of errors can hopefully be eliminated or at least minimized by developing and implementing a careful data collection effort. Elimination of the remaining errors will frequently require the iterative application of the last three steps of the model calibration process - macro-level calibration, sensitivity, and micro-level calibration. Each of these steps is described in the following sections.

A.6 Perform Macro-level Model Calibration

In the event that one or more of the measured state variable values are different from the modeled values by an amount that is deemed to be excessive (i.e greater than 30 percent), it is likely that the cause for the difference may extend beyond errors in the estimates for either the pipe roughness values or the nodal demands. Possible causes for such differences are many but may include: 1) closed or partially closed valves, 2) inaccurate pump curves or tank telemetry data, 3) incorrect pipe sizes (e.g. 6 inch instead of 16, etc.), 4) incorrect pipe lengths, 5) incorrect network geometry, and 6) incorrect pressure zone boundaries, etc. (Walski, 1990a).

The only way to adequately address such errors is to systematically review the data associated with the model in order to insure its accuracy. In most cases, some data will be less reliable than other data. This observation provides a logical place to start in an attempt to identify the problem. Model sensitivity analysis provides another means of identifying the source of discrepancy. For example, if it is suspected that a valve is closed, this assumption can be modeled by simply closing the line in the model and evaluate the resulting pressures. Potential errors in pump curve data may sometimes be circumvented by simulating the pumps with negative inflows set equal to observed pumps discharges (Cruickshank, and Long, 1992). This of course assumes that the errors in the observed flow rates (and the induced head) are less than the errors introduced by using the pump curves. In any rate, only after the model results and the observed conditions are within some reasonable degree of correlation (usually less than 20% error) should the final step of micro-level calibration be attempted.

A.7 Perform Sensitivity Analysis

Before attempting a micro-level calibration, it is helpful to perform a sensitivity analysis of the model in order to help identify the most likely source of model error. This can be accomplished by varying the different model parameters by different amounts and then measuring the associated effect. For example, many current network models have as an

analysis option the capability to make multiple simulations in which global adjustment factors can be applied to pipe roughness values or nodal demand values. By examining such results, the user can begin to identify which parameters have the most significant impact on the model results and thereby identify potential parameters for subsequent fine tuning through micro-level calibration.

A.8 Perform Micro-level Model Calibration

After the model results and the field observations are in reasonable agreement, a micro-level model calibration should be performed. As discussed previously, the two parameters adjusted during this final calibration phase will normally include pipe roughness and nodal demands. In many cases it may be useful to break the micro calibration into two separate steps: 1) steady state calibration, and 2) extended period calibration. In performing a steady state calibration the model parameters are adjusted to match pressures and flowrates associated with static observations. The normal source for such data is from fire flow tests. In an extended period calibration, the model parameters are adjusted to match time varying pressures and flows as well as tank water level trajectories. In most cases the steady state calibration will be more sensitive to changes in pipe roughness while the extended period calibration will be more sensitive to changes in the distribution of demands. As a result, one potential calibration strategy would be to first fine tune the pipe roughness parameter values using the results from fire flow tests and then try to fine tune the distribution of demands using the flow/pressure/water level telemetry data.

Historically, most attempts at model calibration have typically employed an empirical or trial and error approach. Such an approach can prove to be extremely time consuming and frustrating when dealing with most typical water systems. The level of frustration will, of course, depend somewhat on the expertise of the modeler, the size of the system, and the quantity and quality of the field data. Some of the frustration can be minimized by breaking complicated systems into smaller parts and then calibrating the model parameters using an incremental approach. Calibration of multi-tank systems can sometimes be facilitated by collecting multiple data sets with all but one of the tanks closed (Cruickshank, and Long, 1992). In recent years, several researchers have proposed different algorithms for use in automatically calibrating hydraulic network models. These techniques have been based on the use of analytical equations (Walski, 1983), simulation models (Rahal et al., 1980; Gofman and Rodeh, 1981; Ormsbee and Wood, 1986; and Boulos and Ormsbee, 1991), and optimization methods (Meredith, 1983; Coulbeck, 1984, Ormsbee, 1989; Lansey and Basnet, 1991; and Ormsbee, et al., 1992).

A.8.1 Analytical Approaches

In general, techniques based on analytical equations require significant simplification of the network through skeletonization and the use of equivalent pipes. As a result, such

techniques may only get the user close to the correct results. Conversely, both simulation and optimization approaches take advantage of using a complete model.

A.8.2. Simulation Approaches

Simulation techniques are based on the idea of solving for one or more calibration factors through the addition of one or more network equations. The additional equation or equations are used to define an additional observed boundary condition (such as fire flow discharge head). By addition of an extra equation, an additional unknown can then be determined explicitly.

The primary disadvantage of the simulation approaches is that they can only handle one set of boundary conditions at a time. For example, in applying a simulation approach to a system with three different sets of observations (all of which were obtained under different boundary conditions, i.e. different tank levels, pump status, etc.), three different results can be expected. Attempts to obtain a single calibration result will require one of two application strategies: 1) a sequential approach, or 2) an average approach. In applying the sequential approach the system is subdivided into multiple zones whose number will correspond to the number of sets of boundary conditions. In this case the first set of observations is used to obtain calibration factors for the first zone. These factors are then fixed and another set of factors is then determined for the second zone and so on. In the average approach, final calibration factors are obtained by averaging the calibration factors for each of the individual calibration applications.

A.8.3 Optimization Approaches

The primary alternative to the simulation approach is to use an optimization approach. In using an optimization approach, the calibration problem is formulated as a nonlinear optimization problem consisting of a nonlinear objective function subject to both linear and nonlinear equality and inequality constraints. Using standard mathematical notation, the associated optimization problem may be expressed as follows:

Minimize:

$$f(\mathbf{X})$$

..... eq. A.13

Subject To:

$$g(\mathbf{X}) = 0$$

..... eq. A.14

$$L_h \leq h(\mathbf{X}) \leq U_h$$

..... eq. A.15

$$L_x \leq \mathbf{X} \leq U_x$$

..... eq. A.16

where X is the vector of decision variables (pipe roughness coefficients, nodal demands, etc.), f(X) is the nonlinear objective function, g(X) is a vector of implicit system constraints, h(X) is a vector of implicit bound constraints, and, Lx and Ux, are the lower and upper bounds on the explicit system constraints and the decision variables.

Normally, the objective function will be formulated so as to minimize the square of the differences between observed and predicted values of pressures and flows. Mathematically, this may be expressed as:

$$f(\mathbf{X}) = \alpha \sum_{j=1}^{J} (OP_j - PP_j)^2 + \beta \sum_{p=1}^{p} (OQ_p - PQ_q)^2$$

..... eq. A.17

where OPj = the observed pressure at junction j, PPj = the predicted pressure at junction j, OQp = the observed flow in pipe p, PQp = the predicted flow in pipe p, and α and β are normalization weights.

The implicit bound constraints on the problem may include both pressure bound constraints and flowrate bound constraints. These constraints may be used to insure that the resulting calibration does not produce unrealistic pressures or flows as a result of the model calibration process. Mathematically, for a given vector of junction pressures P these constraints can be expressed as:

$$L_p \leq \mathbf{P} \leq U_p$$

..... eq. A.18

Likewise for a given vector of pipe flows Q these constraints can be expressed as:

$$L_Q \leq \mathbf{Q} \leq U_Q$$

..... eq. A.19

The explicit bound constraints may be used to set limits on the explicit decision variables of the calibration problem. Normally, these variables will include (1) the roughness coefficient of each pipe, and (2) the demands at each node. For a given vector of pipe roughness coefficients C these constraints can be expressed as:

$$L_C \leq \mathbf{C} \leq U_C$$

..... eq. A.20

Likewise for a given vector of nodal demands D, these constraints can be expressed as:

$$L_D \leq \mathbf{D} \leq U_D$$

..... eq. A.21

The implicit system constraints include nodal conservation of mass and conservation of energy.

The nodal conservation of mass equation Fc (Q) requires that the sum of flows into or out of any junction node n minus any external demand Dj must be equal to zero. For each junction node j this may be expressed as:

$$F_c(Q) = \sum_{n \in j}^{N_j} Q_n - D_j = 0$$

..... eq. A.22

where Nj = the number of pipes connected to junction node j and {j} is the set of pipes connected to junction node j.

The conservation of energy constraint Fe(Q) requires that the sum of the line loss (HLn) and the minor losses (HMn) over any path or loop k, minus any energy added to the liquid by a pump (EPn), minus the difference in grade between and two points of known energy (DEk) is equal to zero. For any loop or path k this may be expressed as:

$$F_e(Q) = \sum_{n \in k}^{N_k} (HL_n + HM_n - EP_n) - DE_k = 0$$

..... eq. A.23

where Nk = the number of pipes associated with loop or path k, and {k} is the set of pipes associated with loop or path k. It should be emphasized that HLn, HMn, and EPn, are all nonlinear functions of the pipe discharge Q.

While both the implicit and explicit bound constraints have traditionally been incorporated directly into the nonlinear problem formulation, the implicit system constraints have been handled using one of two different approaches. In the first approach, the implicit system constraints are incorporated directly within the set of nonlinear equations and solved using normal nonlinear programming methods. In the second approach, the equations are removed from the optimization problem and evaluated externally using mathematical simulation (Ormsbee, 1989; Lansey and Basnet, 1991). Such an approach allows for a much smaller and more tractable optimization problem, since both sets of implicit equations (which constitute linear and nonlinear equality constraints to the original problem) can now be satisfied much more efficiently using an external simulation model (see Figure A.7). The basic idea behind the approach

is to use an implicit optimization algorithm to generate a vector of decision variables which are then passed to a lower level simulation model for use in evaluating all implicit system constraints. Feedback from the simulation model will include numerical values for use in identifying the status of each constraint as well as numerical results for use in evaluating the associated objective function.

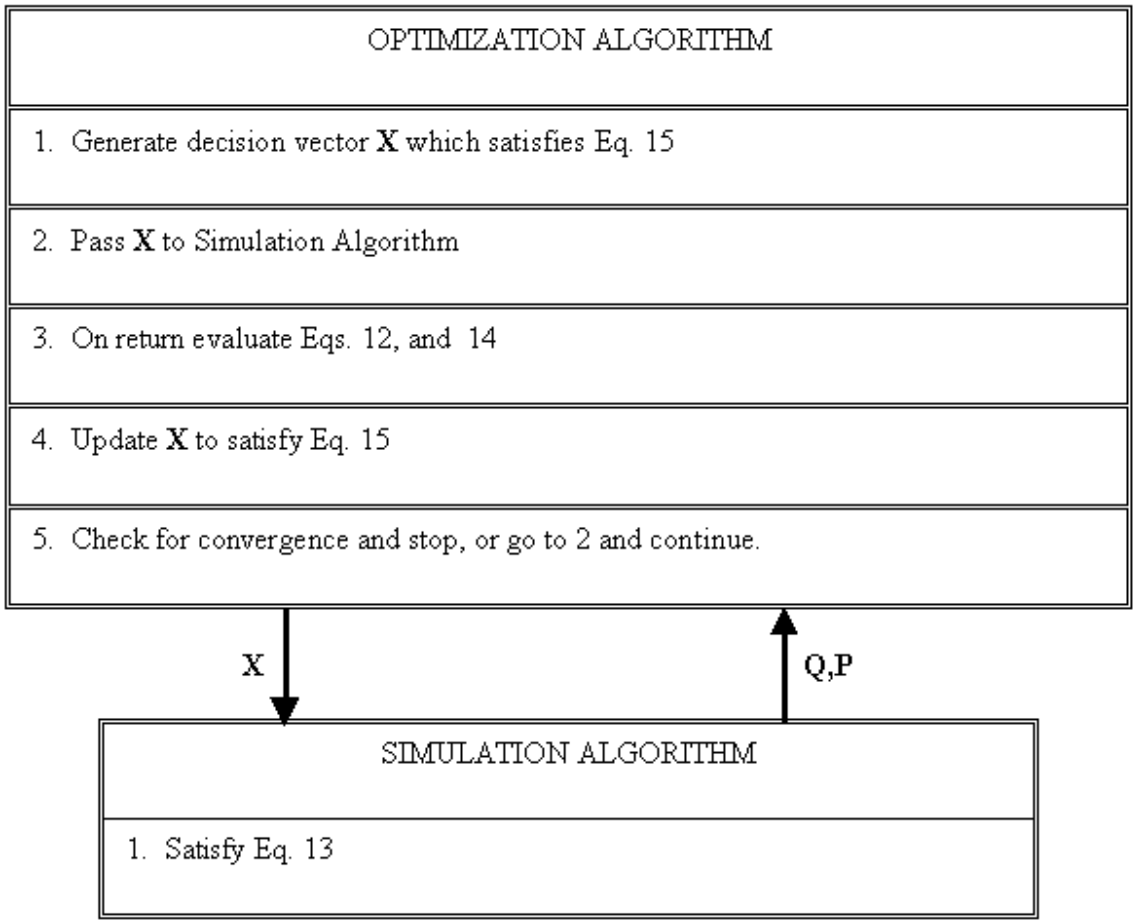
OPTIMIZATION ALGORITHM
1. Generate decision vector X which satisfies Eq. 15
2. Pass X to Simulation Algorithm
3. On return evaluate Eqs. 12, and 14
4. Update X to satisfy Eq. 15
5. Check for convergence and stop, or go to 2 and continue.
X
Q,P
SIMULATION ALGORITHM
1. Satisfy Eq. 13

Figure A.7. Bi-Level Computational Framework

Regardless of which approach is chosen, the resulting mathematical formulation must then be solved using some type of nonlinear optimization method. In general, three different approaches have been proposed and used: (1) gradient based methods, (2) pattern search methods, and (3) genetic optimization methods.

Gradient based methods require either first or second derivative information in order to produce improvements in the objective function. Traditionally, constraints are handled using either a penalty method or the Lagrange multiplier method (Edgar and Himmelblau, 1988). Pattern search methods employ a nonlinear heuristic that uses objective function values only in determining a sequential path through the region of

search (Ormsbee, 1986, Ormsbee and Lingireddy, 1995). In general, when the objective function can be explicitly differentiated with respect to the decision variables the gradient methods are preferable to search methods. When the objective function is not an explicit function of the decision variables, as is normally the case with the current problem, then the relative advantage is not as great, although the required gradient information can still be determined numerically.

Recently, several researchers have begun to investigate the use of genetic optimization for solving such complex nonlinear optimization problems (Lingireddy et.al. 1995, Lingireddy and Ormsbee, 1998, and Savic and Walters 1995). Genetic optimization offers a significant advantage over more traditional optimization approaches in that it attempts to obtain an optimal solution by continuing to evaluate multiple solution vectors simultaneously (Goldberg, 1989). In addition, genetic optimization methods do not require gradient information. Finally, genetic optimization methods employ probabilistic transition rules as opposed to deterministic rules which have the advantage of insuring a robust solution methodology.

Genetic optimization starts with an initial population of randomly generated decision vectors. For an application to network calibration, each decision vector could consist of a subset of pipe roughness coefficients, nodal demands, etc. The final population of decision vectors is then determined through an iterative solution methodology that employs three sequential steps: 1) evaluation, 2) selection, and 3) reproduction. The evaluation phase involves the determination of the value of a fitness function (objective function) for each element (decision vector) in the current population. Based on these elevations, the algorithm then selects a subset of solutions for use in reproduction. The reproduction phase of the algorithm involves the generation of new offspring (additional decision vectors) using the selected pool of parent solutions. Reproduction is accomplished through the process of crossover whereby the numerical values of the new decision vector is determined by selecting elements from two parent decision vectors. The viability of the thus generated solutions is maintained by random mutations that are occasionally introduced into the resulting vectors. The resulting algorithm is thus able to generate a whole family of optimal solutions and thereby increase the probability of obtaining a successful model calibration.

Although optimizations in general and genetic optimization in particular offer very powerful algorithms for use in calibrating a water distribution model, the user should always recognize that the utility of the algorithms are very much dependent upon the accuracy of the input data. Such algorithms can be susceptible to convergence problems when the errors in the data are significant (e.g. headloss is on the same order of magnitude as the error in headloss). In addition, because most network model calibration problems are under-specified (i.e. there are usually many more unknowns than data points), many different solutions (i.e. roughness coefficients, junction demands) can give

reasonable pressures if the system is not reasonably stressed when the field data are collected.

A.9 Future Trends

With the advent and use of nonlinear optimization, it is possible to achieve some measure of success in the area of micro-level calibration. It is of course recognized that the level of success will be highly dependent upon the degree that the sources of macro-level calibration errors have first been eliminated or at least significantly reduced. While these sources of errors may not be as readily identified with conventional optimization techniques, it may be possible to develop prescriptive tools for these problems using expert system technology. In this case general calibration rules could be developed from an experiential data base that could then be used by other modelers in an attempt to identify the most likely source of model error for a given set of system characteristics and operating conditions. Such a system could also be linked with a graphical interface and a network model to provide an interactive environment for use in model calibration.

In recent years, there has been a growing advocacy for the use of both GIS technology and SCADA system databases in model calibration. GIS technology provides an efficient way to link customer billing records with network model components for use in assigning initial estimates of nodal demands (Basford and Sevier, 1995). Such technology also provides a graphical environment for examining the network database for errors. One of the more interesting possibilities with regard to network model calibration is the development and implementation of an on-line network model through linkage of the model with an on-line SCADA system. Such a configuration provides the possibility for a continuing calibration effort in which the model is continually updated as additional data is collected through the SCADA system (Schulte and Malm, 1993).

Finally, Bush and Uber (1998) have developed three sensitivity-based metrics for ranking potential sampling locations for use in model calibration. Although the documented sampling application was small, the developed approach provides a potential basis for selecting improved sampling sites for improved model calibration. It is expected that this area of research will see additional activity in future years.

10 Summary and Conclusion

Network model calibration should always be performed before any network analysis planning and design study. A seven-step methodology for network model calibration has been proposed. Historically, one of the most difficult steps in the process has been the final adjustment of pipe roughness values and nodal demands through the process of micro-level calibration. With the advent of recent computer technology it is now possible to achieve good model calibration with a reasonable level of success. As a result, there

remains little justification for failing to develop good calibrated network models before conducting network analysis. It is expected that future developments and applications of GIS and SCADA technology, as well as optimal sampling algorithms will lead to even more efficient tools.

A.11 Appendix A References

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Appendix B: C-Factor testing standard procedure and Data Collection Sheets

B.1. Two Gage C-Factor Test

Two gage C-factor tests will be done in accordance with American Water Works Association M32-Computer Modeling of Water Distribution Systems and M17 guide-Installation, Field Testing, and Maintenance of Fire Hydrants. A step by step procedure for conducting the C-Factor Test is shown below.

Hydrant Testing Crew Instructions

1. Test shall be made during a period of ordinary demand. Before testing begins the Nicholasville WTP plant will need to be notified of the time of testing. This is so the Nicholasville WTP can record the required data regarding tank levels, pump operation schedules, plant flow, etc during each hydrant flow test.

2. Two hydrants, designated the "Residual Hydrants", will be chosen to collect the normal static pressure while the other hydrant in the group are closed. The residual pressure will also be collected while the other hydrant in the group is flowing. Record the length between these hydrants. The length between these two hydrants should range between 400 and 1200 feet. If the hydrants are not at the same elevation, height of the hydrants will need to be recorded.

3. One hydrant, designated the "Flow Hydrant", is chosen to be the hydrant where flow pressure will be observed, using a Pitot tube (Hydrant Flow Meter). The Pitot tube to be used for this project is a Pollard P669LF.

4. Once the flow hydrant has been selected, a valve directly downstream of the flow hydrant should be closed. The valve should be closed slowly to prevent pressure surges and water hammers in the system.

5. A 2 ½" cap with pressure gauge that can read approximately 25 psi greater than the system pressure for the hydrant will be attached to the residual hydrants and the hydrant opened full. For this project a Pollard item # P67022LF hydrant static pressure gage will be used. A reading (static pressure) is taken when the needle comes to a rest. Record this reading on the Hydrant Flow Test Work Sheet.

6. The hydrant testing crew members for the residual hydrants will then signal the flowing hydrant crew member using 2 way radio device or cell phone. At this time the flowing hydrant shall be opened, water should be allowed to flow long enough to clear any debris and foreign substances from stream. After this task is performed close the hydrant and attach the Pitot tube to the 2 ½" outlet and open hydrant again. The hydrant should be flowed approximately 2-5 minutes. The hydrant valve should be opened slowly to prevent pressure surges or water hammer in the system.

6.b If dechlorination regulations exist for the selected hydrant then dechlorinating diffuser will need to be connected to the flowing hydrant.

7. Observe the pitot gauge reading and record the pressures at the residual hydrant and the flowing hydrants simultaneously. Proper communication will be needed to achieve simultaneous recording.

8. Complete the other necessary information on the Hydrant Flow Test Work Sheet.

9. Make sure to reopen the previously closed valve before leaving the testing site.

Water Treatment Plant Crew Instruction

1. Once notified of Hydrant testing. The real time data of the plant should begin being recorded. Flow data, tank levels, pump operations data should be taken approximately one hour before the actual hydrant testing is scheduled to take place.
2. After initial parameters have been recorded, real time data should be taken in 15 minute intervals. Communication with the hydrant crew will help synchronize when readings should be collected.

The C-factor test data sheets are shown on the next page.

C-Factor Data Collection Log

Site ID _____

Flowing Hydrant

Nicholasville Hydrant #: _____
Project Hydrant ID: _____
Hydrant Location:_____
_____
Gage Elevation: _____
Equipment ID: _____

Residual Hydrant #1

Nicholasville Hydrant #: _____
Project Hydrant ID:
Hydrant Location:_____
_____
Gage Elevation: _____
Equipment ID:

Residual Hydrant #2

Nicholasville Hydrant #: _____
Project Hydrant ID:_____
Hydrant Location:_____
_____
Gage Elevation: _____
Equipment ID:_____

Date	Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Static Pressure (psi)	Residual Pressure (psi)	Static Pressure (psi)	Residual Pressure (psi)
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							
	:							

Distance Between Residual Hydrant #1 and Residual Hydrant #2: _____
Projected Results at 20 Psi Residual: _____ gpm, or at _____ psi Residual _____ gpm

Remarks:

C-Factor Data Collection Log (1 of 2)

C-Factor Data Collection Log

Tank Levels (ft) **Pump Operations**

Date	Time	Stephens Drive	Lake Street	Capital Court	Pump 1 Flow (gpm)	Pump 2 Flow (gpm)	Pump 3 Flow (gpm)	Pump 4 Flow (gpm)	Pump 5 Flow (gpm)
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								

Corresponding Flow Hydrant: _____ Corresponding Residual Hydrant: _____
Consumption Rate during Test _____
Remarks:

C-Factor Data Collection Log (2 of 2)

Appendix C: Fire Flow Testing Standard Procedures and Data Collection Sheets

C. Sample Collection, Preparation, and Recording Procedures

C.1. Fire Flow Test

Fire Flow test will be done in accordance with AWWA M17 guide- Installation, Field Testing, and Maintenance of Fire Hydrants. A step by step procedure for conducting the fire flow test is shown below.

Hydrant Testing Crew Instructions

1. Test shall be made during a period of ordinary demand. Before testing begins the Nicholasville WTP plant will need to be notified of the time of testing. This is so the Nicholasville WTP can record the required data regarding tank levels, pump operation schedules, plant flow, etc during each hydrant flow test.

2. One hydrant, designated the "Residual Hydrant", will be chosen to collect the normal static pressure while the other hydrants in the group are closed. The residual pressure will also be collected while the other hydrant in the group is flowing. If the hydrants are not at the same elevation, height of the hydrants will need to be recorded.

3. One hydrant, designated the "Flow Hydrant", is chosen to be the hydrant where flow pressure will be observed, using a Pitot tube (Hydrant Flow Meter). The Pitot tube to be used for this project is a Pollard P669LF.

4. A 2 ½" cap with pressure gauge that can read approximately 25 psi greater than the system pressure for the hydrant will be attached to the residual hydrant and the hydrant opened full. For this project a Pollard item # P67022LF Hydrant Static Pressure gage will be used. A reading (static pressure) is taken when the needle comes to a rest. Record this reading on the Hydrant Flow Test Work Sheet.

5. The hydrant testing crew members for the residual hydrant will then signal the flowing hydrant crew member using 2 way radio device or cell phone. At this time the flowing hydrant shall be opened, water should be allowed to flow long enough to clear any debris and foreign substances from stream. After this task is performed close the hydrant and attach the pitot tube to the 2 ½" outlet and open hydrant again. The hydrant should be flowed approximately 2-5 minutes. The hydrant valve should be opened slowly to prevent pressure surges or water hammer in the system.

5.b If dechlorination regulations exist for the selected hydrant then dechlorinating diffuser will need to be connected to the flowing hydrant.

6. Observe the pitot gauge reading and record the pressures at the residual hydrant and the flowing hydrants simultaneously. Proper communication will be needed to achieve simultaneous recording.

7. Complete the other necessary information on the Hydrant Flow Test Work Sheet. Calculation for the available flow at a 20 psi residual can be found in section C.2

Water Treatment Plant Crew Instruction

1. Once notified of Hydrant testing. The real time data of the plant should begin being recorded. Flow data, tank levels, pump operations data should be taken approximately one hour before the actual hydrant testing is scheduled to take place.
2. After initial parameters have been recorded real time data should be taken in 15 minute intervals. Communication with the hydrant crew will help synchronize when readings should be collected.

The fire flow test data sheet is shown on the next page.

Fire Flow Data Collection Log

Site ID: _____

Flowing Hydrant

Nicholasville Hydrant #: _____
Project Hydrant ID:_____
Hydrant Location:_____
_____
Gage Elevation: _____
Equipment ID: _____

Residual Hydrant

Nicholasville Hydrant #: _____
Project Hydrant ID:_____
Hydrant Location:_____
_____
Gage Elevation: _____
Equipment ID: _____

Date	Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						
	:						

Projected Results at 20 Psi Residual: _____ gpm, or at _____ psi Residual _____ gpm

Remarks:

Fire Flow Data Collection Log (1 of 2)

Fire Flow Data Collection Log

Site ID: _____

Tank Levels (ft) **Pump Operations**

Date	Time	Stephens Drive	Lake Street	Capital Court	Pump 1 Flow (gpm)	Pump 2 Flow (gpm)	Pump 3 Flow (gpm)	Pump 4 Flow (gpm)	Pump 5 Flow (gpm)
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								
	:								

Corresponding Flow Hydrant: _____ Corresponding Residual Hydrant: _____
Consumption Rate during Test _____
Remarks:

Fire Flow Data Collection Log (1 of 2)

C.2. Calculation of Available Flow for a 20 psi Residual Pressure

AVAILABLE FLOW

This is the calculated maximum capacity of the hydrant if it is pumped down to the basis residual pressure (usually 20 psi).

Q FORMULA

The Q formula produces a value in GPM based on the nozzle diameter and pitot pressure (solving for "Q".)

$$Q = 29.83\ cd^2\sqrt{p} = Q_F$$

Where Q=observed flow, c=coefficient, d=outlet diameter, p=pitot pressure.

HAZEN-WILLIAMS FORMULA

This formula calculates available flow based on the readings taken before and during the single outlet flow test (solving for "QR".)

$$Q_R = Q_F \times \frac{h_r^{0.54}}{h_f^{0.54}}$$

Q_F = Observed Flow
h_r = pressure drop from the static pressure to the desired residual pressure (psi)
h_f = pressure drop from static pressure to actual residual pressure recorded (psi)

Example:

Static Pressure: 68 psi
Residual Pressure: 43 psi
Total Field Flow = 1710
Desired Residual Pressure = 20 psi

$Q_R = 1710 * \left(\frac{(68-20)^{.54}}{(68-43)^{.54}}\right) = 2430$ gpm*

*This is under the assumption the boundary conditions like the tank levels are not changing drastically.

C.3. Possible Problems and Contingencies

The Figure shown below, addresses possible problems with hydrant testing and actions taken to remedy and prevent the problems from occurring.

Possible Problems	Consequences	Possible Cause	Preventive Action	Contingent Action
Dumping Chlorines and Chloramines into a sensitive environment	Can kill wildlife, fragile plants, etc.	Too much Chlorine in the System, or did not anticipate environmental sensitivity	Install diffuser baskets on the end of your hydrants with chlorine neutralizing tablets.	Attempt to clean up the dumped chlorine and chloramines damage and/or attempt to neutralize its effects.
Down Stream Flooding/Run-off	Property is flooded	Incorrectly estimated where the downstream water would go. Or used too much water	Add a hose to the end of the Fire Hydrant Discharge and direct the flow to the desired drainage point	Immediately Shut the fire hydrant off and try to divert the runoff to the desired drainage point
Mechanical Problems with the Water System (Closed Values, excess debris in system, etc.)	Hydrant Flow values are less than they should be an you get inaccurate information	Prior construction to the system. Valves not fully open, Poorly installed hydrant, debris in pipes	Come up with an initial guess to make sure values are close, check for previous construction in the area, inspect hydrant for flaws.	Preform the test at multiple sites to determine if the problem occurs in other areas of the system
Poor Instrumentation	Inaccurate Readings	Did not properly calibrate instruments. Did not correctly setup/install instruments	Calibrate instruments before use, have an experienced member set up the installation.	Check your instrument to see if it did have errors and adjust results accordingly.
Inaccurate Record Keeping	Inaccurate information	Human Error, Fatigue, Lack of attention to detail	Have two people record the data and compare.	Redo the fire flow test

Hydrant Testing Information

Appendix D: Tracer Testing Procedures and Data Collection Sheets

D.1. Tracer Test

The tracer test should be performed according to the following steps shown below. The steps summarize the procedure and may not be inclusive of every individual task that needs to be performed. In this instance all procedures and information should be confirmed with the appropriate personnel before advancing to the next step.

Performing an Injection- Water Treatment Plant Crew

1. The operator and the water treatment crew should review and be familiar with the contingency plan to help ensure the health and safety of the public.
2. The required tracer injection equipment should be checked to ensure it is performing as expected.
3. Finished water in the water distribution should be collected. This information should be recorded on the appropriate data collection sheet.
4. At the designated time the injected fluoride concentration should be shut off. This information should be communicated with the field crew so that field crew will know when to begin collecting data.
5. Sampling of the finished water should continue until the concentration of the finished water reaches background levels (raw water levels).
6. Once the water in the distribution system has reached background levels. The fluoride injection pump should be turned back on.
7. The pump should run until the concentration of the finished water reaches the predetermined level. (1.2 mg/L). The injected concentration should be same throughout the injection process.
8. Careful sampling should occur to ensure that the concentration does not exceed this level/ and or does not exceed MCL levels.
9. All necessary data should be recorded on the appropriate data sheet.

Hydrant Testing Field Crew Instructions

1. The field crew should become familiar with the contingency plan in the event of a hydrant malfunction; fluoride exceeds maximum levels, etc to help ensure the health and safety of the public.
2. The field crew should install and calibrate the appropriate equipment onto each hydrant/tap.

3. Members of the hydrant testing field crew should check each hydrant. This involves exercising the hydrant valve and flushing the main to ensure there are no particles that have collected.
4. Once the hydrant has been flushed a gate valve should be installed on the hydrant. Field testing personnel should become familiar with how to properly flow and operate the hydrant during the actual test.
5. Each hydrant or tap will be required to be flowed at a certain rate in order to collect a good representative sample. This rate will be predetermined and provided to each member of the testing crew. For more information on how to operate the hydrant and how this flow rate was calculated refer to Appendix H.
6. A sign should be placed on every hydrant explaining to the general public that the hydrant is being used and contact information in case problems arise with the hydrant.
7. The fluoride concentration measuring device should be properly calibrated using 1.0 mg/L fluoride solution samples.
8. Once the tracer study has begun each field team member should at the appropriate time interval flow the hydrant and collect a 100ml grab sample. The appropriate data collection forms should be filled out.
9. Once the sample is collected the lid should be fastened tightly and the grab sample should be properly marked. Once the sample has been labeled it should be placed in a cooler at approximately 4ºC (39º F).
10. This procedure should be repeated at each designated time interval.
11. Some field testing crew members will be moving from site to site testing various grab samples with the fluoride colorimeter.
12. If it is discovered that the fluoride concentration is above 1.2 mg/L then the water treatment plant should be contacted immediately.
13. Each hydrant should be checked to determine if the hydrant is operating properly. If not a staff person should be sent to the hydrant immediately to address the issue.
14. Once the tracer study is complete, the grab samples should be transported to the lab at the University of Kentucky. All hydrant equipment should be removed from the hydrant.
15. All necessary data should be filled out on the appropriate forms.

Appendix E: Hach Fluoride Pocket Colorimeter II- Field Testing Protocol

This Appendix contains the procedures for measuring fluoride concentrations with the Hach Fluoride Pocket Colorimeter II. The first method discussed is the SPADNS Method and the second method discussed is AccuVac Method. The following information is taken from the Hach Pocket Colorimeter Instruction Manual. Refer to the entire instructional manual provided at www.hach.com for more information regarding the Hach Fluoride Colorimeter II.

Fluoride, Pipet Method (0.02 to 2.00 mg/L F^-)

Method 8029

For water, wastewater, and seawater

SPADNS Method* USEPA Accepted (distillation required)

Measuring Hints

- Remove liquid and fingerprints from the sample cells with a soft, dry cloth before placing in the instrument.
- If samples cannot be analyzed immediately, see Sampling and Storage on page 1—30.
- SPADNS Reagent contains sodium arsenite. Final solutions will contain arsenic (D004) in sufficient concentration to be regulated as a hazardous waste for Federal RCRA.

Note: *The Pocket Colorimeter II is designed to measure solutions contained in sample cells.* ***DO NOT*** *dip the meter in the sample or pour the sample directly into the cell holder.*

* Adapted from *Standard Methods for Examination of Water and Wastewater.*

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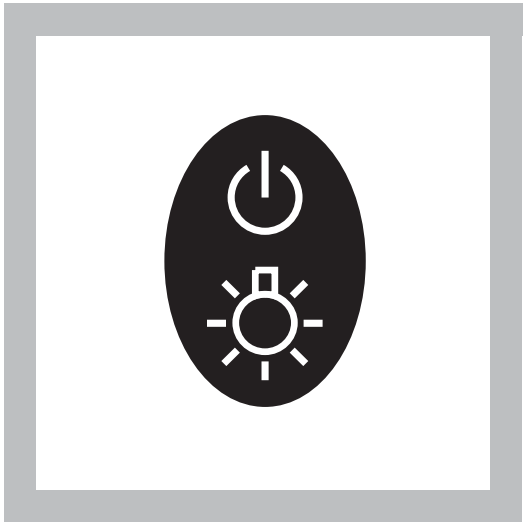
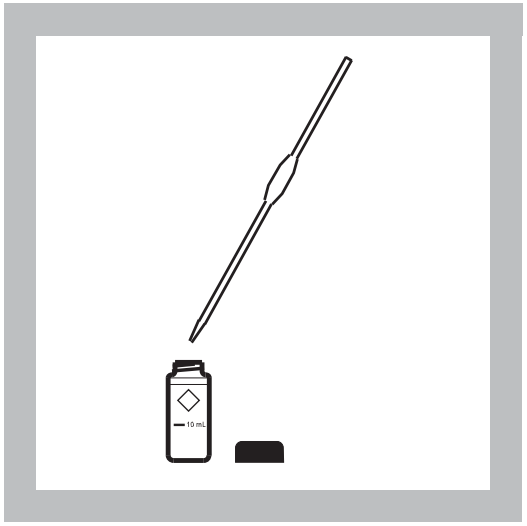


1. Press the **POWER** key to turn the meter on.

The arrow should indicate channel 1.

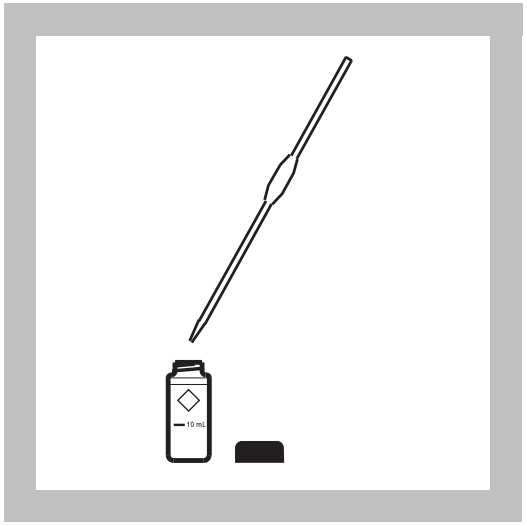
Note: *See page 2—4 for information on selecting the correct range channel.*



2. Use a pipet and pipet filler to transfer 10.0 mL of deionized water into a clean, dry sample cell (the blank).

Note: *The sample and water should be the same temperature (± 1 °C).*

Note: *Volume measurements are extremely critical.*



3. Rinse the 10-mL pipet several times with small portions of the sample. Transfer 10.0 mL of sample into another clean, dry sample cell (the prepared sample).

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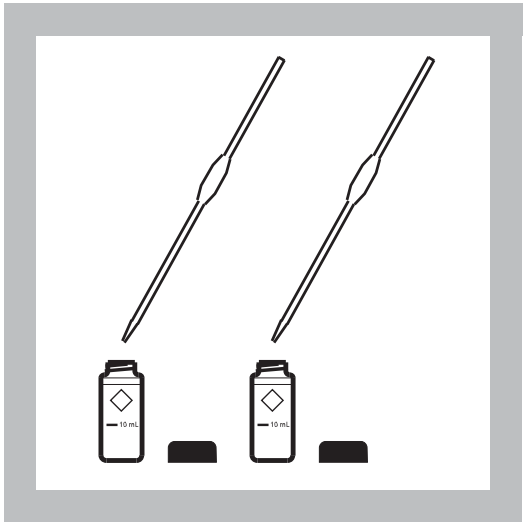
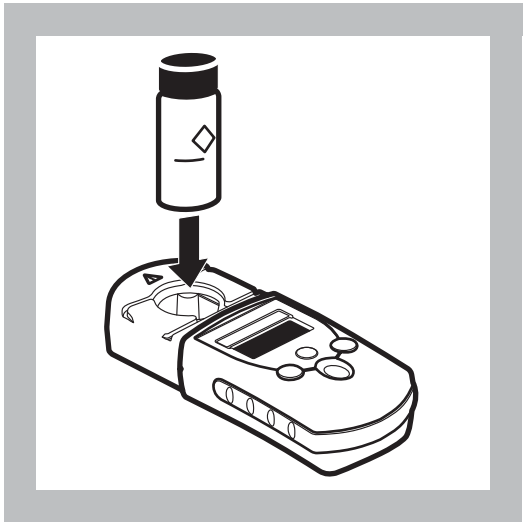


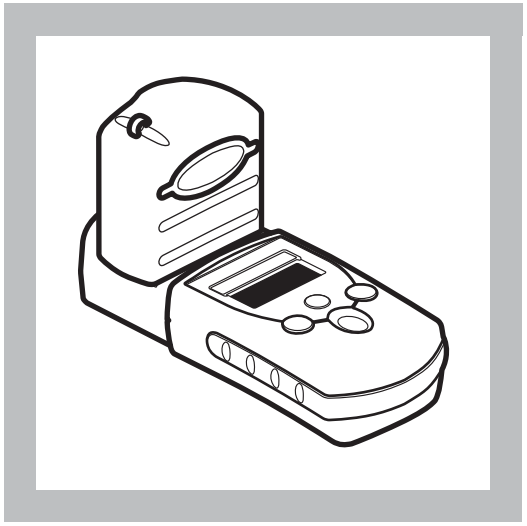
4. Use a pipet filler and 2-mL Class A volumetric pipet to transfer 2.0 mL of SPADNS Reagent into each sample cell. Cap and swirl to mix.

Note: *SPADNS is toxic and corrosive; use care while measuring.*

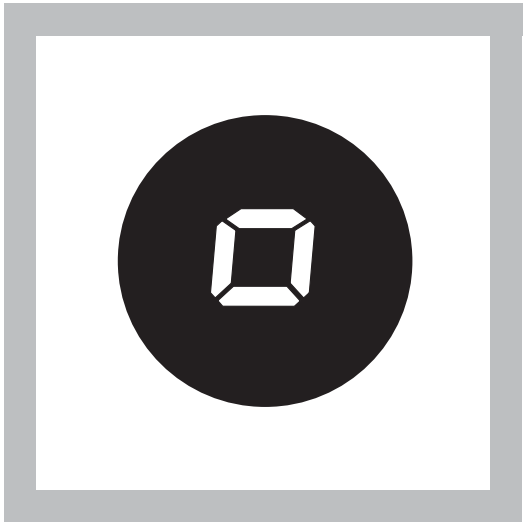
5. Wait 1 minute.



6. Place the blank in the cell holder.



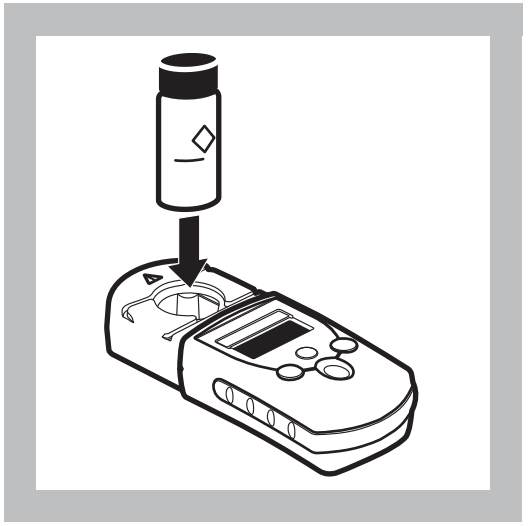
7. Cover the blank with the instrument cap.



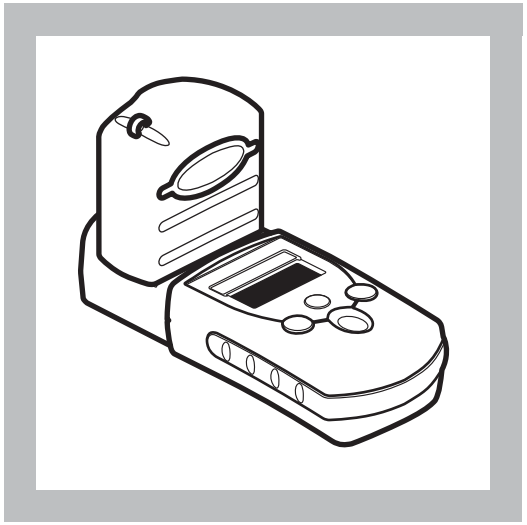
8. Press **ZERO/SCROLL**.

The display will show "- - - -" then 0.00.

Remove the blank from the cell holder.



9. Place the prepared sample in the cell holder.



10. Cover the sample cell with the instrument cap.

11. Press **READ/ENTER**.
The display will show "- - - -", followed by results in mg/L fluoride (F^-).

Note: *If the instrument shows a flashing 2.20 (over range), dilute the sample with an equal volume of water and repeat the test. Multiply the result by 2.*

Sampling and Storage

See Sampling and Storage on page 1–30.

Accuracy Check

See Accuracy Check on page 1–30.

Method Performance

See Method Performance on page 1–31.

Standard Calibration Adjust

See Standard Calibration Adjust on page 2–13.

Interferences

See Interferences on page 1–33.

Distillation Procedure

See Distillation Procedure on page 1–35.

Summary of Method

See Summary of Method on page 1–36.

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Required Reagents

Description	Units	Cat. No.
SPADNS Reagent Solution for Fluoride	500 mL	444-49
Water, deionized	4 L	272-56

Required Apparatus

Pipet Filler, safety bulb	each	14651-00
Pipet, volumetric, Class A, 2.0 mL	each	14515-36
Pipet, volumetric, Class A, 10.0 mL	each	14515-38
Thermometer, -10 to 110 °C	each	1877-01

Optional Reagents

Drinking Water Quality Control Standard, mixed parameter (1 mg/L Fluoride, 2 mg/L Nitrate, 2 mg/L Phosphate, 50 mg/L Sulfate)	500 mL	28330-49
Fluoride Standard Solution, 0.5 mg/L F^-	500 mL	405-05
Fluoride Standard Solution, 1.0 mg/L F^-	500 mL	291-49
Fluoride Standard Solution, 1.0 mg/L F^-	1000 mL	291-53
Fluoride Standard Solution, 1.5 mg/L F^-	500 mL	405-15

Optional Reagents, continued

Description	Units	Cat. No.
Silver Sulfate, ACS	113 g	334-14
Sodium Arsenite Solution	100 mL MDB	1047-32
Spec√ ™ Secondary Standards Kit, Fluoride	each	27125-00
StillVer® Distillation Solution	500 mL	446-49

Optional Apparatus

Cylinder, graduated, 100 mL	each	508-42
Cylinder, graduated, 250 mL	each	508-46
Distillation Heater and Support Apparatus Set, 115 V ac	each	22744-00
Distillation Heater and Support Apparatus Set, 230 V ac	each	22744-02
Distillation Apparatus General Purpose Accessories	each	22653-00

Replacement Parts

Batteries, AAA, alkaline	4/pkg	46743-00
Instrument Cap/light shield	each	59548-00
Instrument Manual	each	59575-88
Sample Cell, 10-mL, with cap	6/pkg	24276-06

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Fluoride, AccuVac® Method (0.1 to 2.0 mg/L F^-)

Method 8029

For water, wastewater, and seawater

SPADNS AccuVac® Method* USEPA Accepted (distillation required)

Measuring Hints

- Remove liquid and fingerprints from the sample cells with a soft, dry cloth before placing in the instrument.
- If samples cannot be analyzed immediately, see Sampling and Storage on page 1—30.
- The optional AccuVac® Snapper simplifies testing by retaining the broken tip, minimizing exposure to the sample, and providing controlled conditions for filling the ampule.
- SPADNS Reagent contains sodium arsenite. Final solutions will contain arsenic (D004) in sufficient concentration to be regulated as a hazardous waste for Federal RCRA.

Note: *The Pocket Colorimeter II is designed to measure solutions contained in sample cells.* ***DO NOT*** *dip the meter in the sample or pour the sample directly into the cell holder.*

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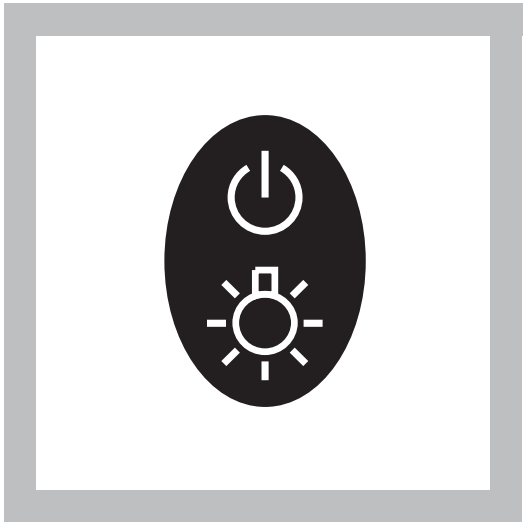
* Adapted from *Standard Methods for Examination of Water and Wastewater.*

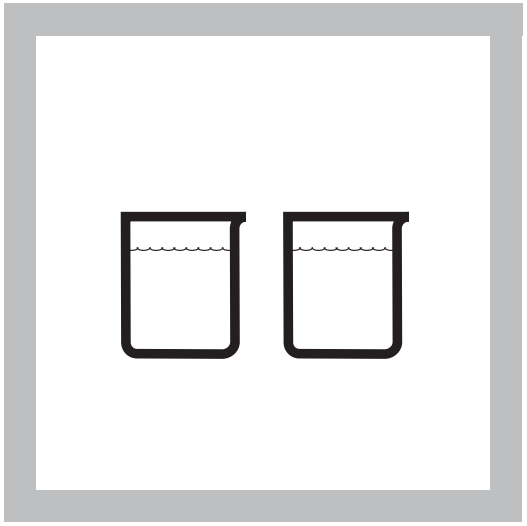
Fluoride, AccuVac® Method, continued



1. Press the **POWER** key to turn the meter on.

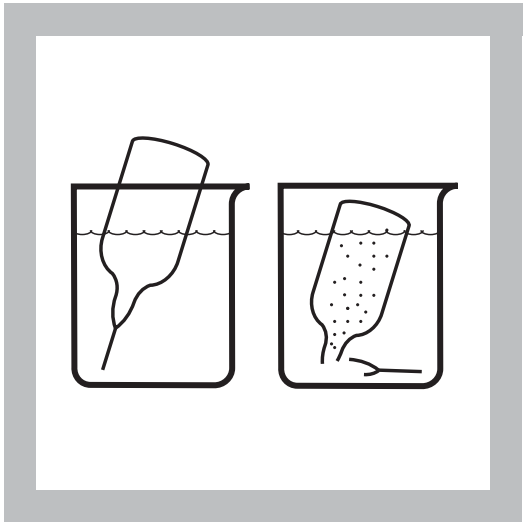
The arrow should indicate channel 2.

Note: *See page 2—4 for information on selecting the correct range channel.*



2. Collect at least 40 mL of sample in a 50-mL beaker. Fill another 50-mL beaker with at least 40 mL of deionized water.

Note: *The sample and water should be the same temperature (± 1 °C).*



3. Fill a SPADNS Fluoride AccuVac Ampul with sample. Fill another SPADNS Fluoride AccuVac Ampul with deionized water (the blank).

Note: *Keep the tip of the ampule immersed until the ampule fills completely.*

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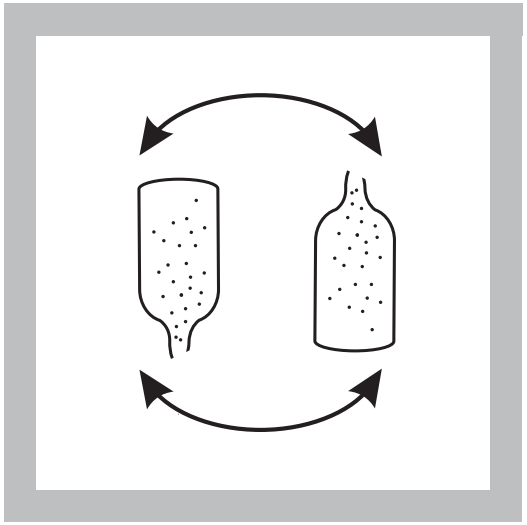
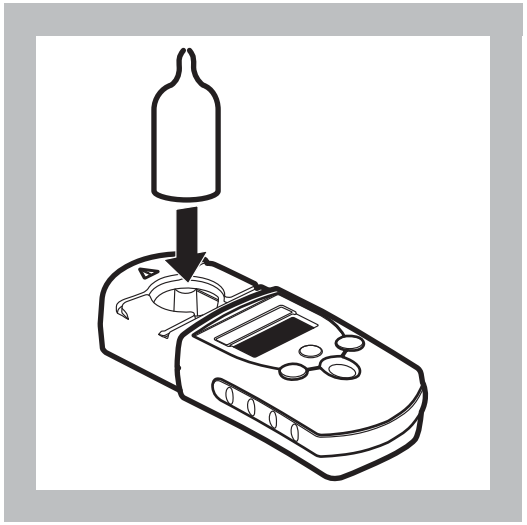


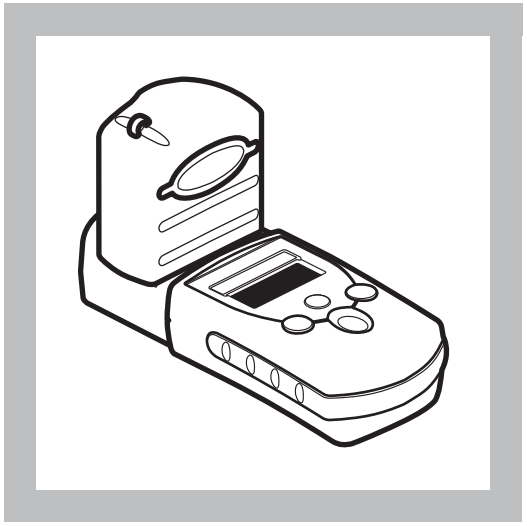
4. Quickly invert the ampuls several times to mix.

Note: *Wipe off any liquid or fingerprints.*

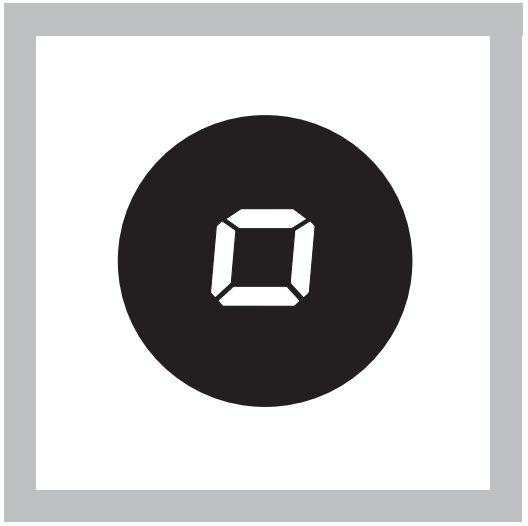
5. Wait 1 minute.



6. Place the blank in the cell holder.



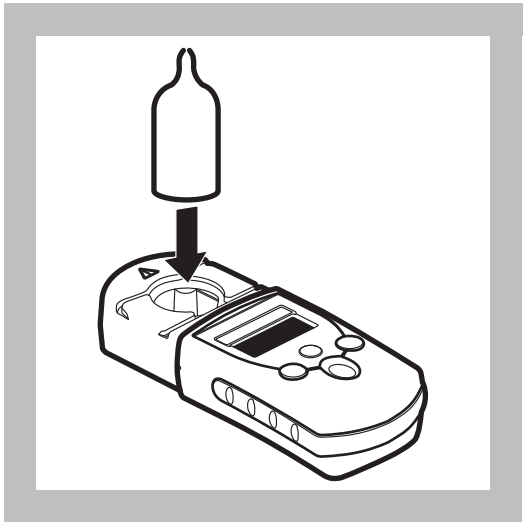
7. Cover the blank with the instrument cap.



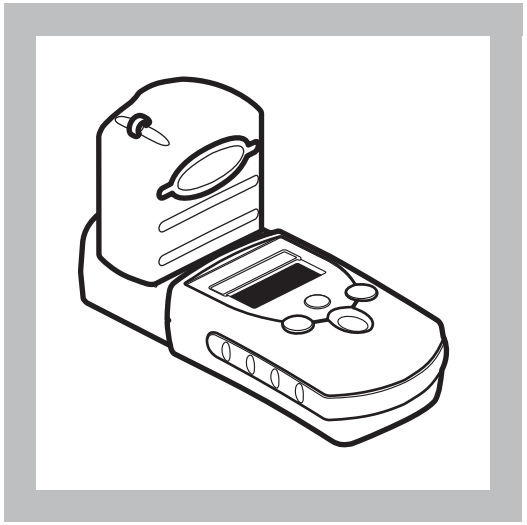
8. Press **ZERO/SCROLL**.

The display will show "- - - -" then 0.0.

Remove the blank from the cell holder.



9. Place the prepared sample in the cell holder.



10. Cover the sample cell with the instrument cap.

11. Press **READ/ENTER**.

The display will show "- - - -", followed by results in mg/L fluoride (F^-).

Note: *If the instrument shows a flashing 2.2 (over range), dilute the sample with an equal volume of water and repeat the test. Multiply the result by 2.*

Sampling and Storage

Samples may be stored in glass or plastic bottles for at least 7 days when cooled to 4 °C (39 °F) or lower. Warm samples to room temperature before analysis.

Accuracy Check

Standard Solutions Method

Use a 1.00 mg/L fluoride standard solution in place of the sample. Perform the procedure as described above.

A variety of standard solutions covering the entire range of the test is available from Hach. Use these in place of the sample to verify technique.

Note: *Minor variations between lots of reagent become measurable above 1.5 mg/L. While results in this region are usable for most purposes, better accuracy may be obtained by diluting a fresh sample 1:1 with deionized water and re-testing. Multiply the result by 2.*

Multiparameter standards that simulate typical drinking water concentrations without dilution are available to confirm test results. See Optional Reagents on page 1—37.

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Method Performance

Typical Precision (95% Confidence Interval):

1.0 ± 0.1 mg/L F^- (AccuVac Ampul)

1.00 ± 0.06 mg/L F^- (Solution)

Estimated Detection Limit:

EDL = 0.1 AccuVac Ampul Method

EDL = 0.03 Solution Method

Standard Calibration Adjust Method

To perform a standard calibration adjustment using the prepared 1.0 mg/L standard or using an alternative standard concentration, see Standard Calibration Adjust on page 2—13.

Spec√™ Secondary Standards

Note: *Due to improvements in the optical system of the Pocket Colorimeter™ II, the tolerance ranges and values on the Certificate of Analysis of previously purchased Spec √ standards may no longer be valid. Obtain a new set of standards, or use the Pocket Colorimeter II to assign new values to existing standards.*

Spec√ Secondary Standards are available to quickly check the repeatability of the Pocket Colorimeter™ II instrument. After initial measurements for the Spec√ standards are collected, the standards can be re-checked as often as desired to ensure the instrument is working consistently.

The Spec√ standards are intended to verify meter performance and do not ensure reagent quality, nor do they ensure the accuracy of the test results. Analysis of real standard solutions using the kit reagents is required to verify the accuracy of the entire Pocket Colorimeter system. The Spec√ Standards should *NEVER* be used to calibrate the instrument. The certificate of analysis lists the expected value and tolerance for each Spec√ Standard.

Using the Spec√ Standards for Instrument Verification

1. Place the Spec√ STD 1 into the cell holder with the alignment mark facing the keypad. Tightly cover the cell with the instrument cap.

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2. Press **ZERO**. The display will show “0.00” or “0.0” depending on the range.
3. Place the blank cell into the cell holder. Tightly cover the cell with the instrument cap.
4. Press **READ/ENTER**. Record the concentration measurement.
5. Repeat steps 1–4 with cells labeled STD 2 and STD 3.
6. Compare these measurements with previous measurements to verify the instrument is performing consistently. (If these are the first measurements, record them for comparison with later measurements.)

Note: *If the instrument is user-calibrated, initial standard measurements of the Spec√ Standards will need to be performed again for the user calibration.*

Interferences

Sample containers and other glassware used must be very clean. If possible, use items for fluoride tests only. Wash potentially contaminated containers with 1:1 nitric acid or hydrochloric acid. Then rinse thoroughly with deionized water. To eliminate uncertainty about container effect, repeat the test using the same container. Consistent results indicate no container contamination.

This test is sensitive to small amounts of interference. The following substances interfere to the extent shown:

	Concentration	Error (mg/L F^-)
Alkalinity (as $CaCO_3$)	5000 mg/L	–0.1
Aluminum	0.1 mg/L	-0.1
Chloride	7000 mg/L	+0.1
Iron, ferric	10 mg/L	-0.1
Phosphate, ortho	16 mg/L	+0.1
Sodium Hexametaphosphate	1.0 mg/L	+0.1
Sulfate	200 mg/L	+0.1

SPADNS Reagent contains enough arsenite to eliminate interference from up to 5 mg/L chlorine. For higher chlorine concentrations, add 1 drop of Sodium Arsenite Solution to 25 mL of sample for each additional 2 mg/L of chlorine.

To check for interference from aluminum, read the concentration 1 minute after mixing the reagent solution (step 4), then again after 15 minutes. An appreciable increase in concentration suggests aluminum interference. Waiting 2 hours before making the final reading will eliminate the effect of up to 3.0 mg/L aluminum.

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Distillation Procedure

(Requires Distillation Heater and Support Apparatus Set)

Most interferences can be eliminated by distilling the sample from an acid solution as described below:

1. Set up the distillation apparatus for the general purpose distillation. See the Distillation Apparatus Manual. Turn on the water and make sure it is flowing through the condenser.
2. Measure 100 mL of sample into the distillation flask. Add a magnetic stir bar and turn on the heater power switch. Turn the stir control to 5. Carefully measure 150 mL of StillVer® Distillation Solution (2:1 sulfuric acid) into the flask. If high levels of chloride are present, add 5 mg of silver sulfate for each mg/L chloride present.
3. Turn the heat control setting to 10, with the thermometer in place. The yellow pilot lamp lights when the heater is on.
4. When the temperature reaches 180° C (approximately one hour), turn the still off. Analyze the distillate by the above method.

Summary of Method

The SPADNS method for fluoride determination involves the reaction of fluoride with a red zirconium-dye solution. The fluoride combines with part of the zirconium to form a colorless complex, thus bleaching the red color in proportion to the fluoride concentration. This method is accepted by the USEPA for NPDES and NPDWR reporting purposes when the samples have been distilled. Seawater and wastewater samples require distillation. See Optional Apparatus on page 1—37 for information on the Distillation Heater and Support Apparatus Set.

Required Reagents

Description	Units	Cat. No.
SPADNS Fluoride Reagent AccuVac® Ampuls	25/pkg	25060-25
Water, deionized	4 L	272-56

Required Apparatus

Beaker, 50 mL, pp	each	1080-41
Thermometer, -10 to 110 °C	each	1877-01

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Optional Reagents

Description	Units	Cat. No.
Drinking Water Quality Control Standard, mixed parameter 1 mg/L Fluoride, 2 mg/L Nitrate, 2 mg/L Phosphate, 50 mg/L Sulfate)	500 mL	28330-49
Fluoride Standard Solution, 0.5 mg/L F^-	500 mL	405-05
Fluoride Standard Solution, 1.0 mg/L F^-	500 mL	291-49
Fluoride Standard Solution, 1.0 mg/L F^-	1000 mL	291-53
Fluoride Standard Solution, 1.5 mg/L F^-	500 mL	405-15
Silver Sulfate, ACS	113 g	334-14
Sodium Arsenite Solution	100 mL MDB	1047-32
Spec√™ Secondary Standards Kit, Fluoride	each	27125-00
StillVer® Distillation Solution	500 mL	446-49

Optional Apparatus

Description	Units	Cat. No.
AccuVac® Snapper Kit	each	24052-00
Cylinder, graduated, 100 mL	each	508-42
Cylinder, graduated, 250 mL	each	508-46

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Optional Apparatus, continued

Description	Units	Cat. No.
Distillation Heater and Support Apparatus Set, 115 V ac	each	22744-00
Distillation Heater and Support Apparatus Set, 230 V ac	each	22744-02
Distillation Apparatus General Purpose Accessories	each	22653-00

Replacement Parts

Batteries, AAA, alkaline	4/pkg	46743-00
Instrument Cap/light shield	each	59548-00
Instruction Manual	each	59575-88
Sample Cell, 10-mL, with cap	6/pkg	24276-06

Appendix F: Calibration Equipment

Table F.1 shown below list the equipment along with the supplier and item number.

Table F.1 Equipment List

Field Testing Supplies	Supplier	Item #
1. Hydrant Flow Meter	Pollard	P669LF
2. Hydrant Static Pressure Gage	Pollard	P67022LF
3. Pressure Snubbers	Pollard	P605
4. Hydrant Wrenches	Pollard	P66602
5. Dechlorinating Diffuser	Pollard	LPD-250
6. LPD Pitot Kit	Pollard	LPDPITOTKIT
7. LPD-Chlor Tablets 1 Pail	Pollard	W0000010
8. FHG with Digital Pressure Loggers 0-300 psi	Pollard	FHGPR325
9. Software & Download Cable	Pollard	A016
10. Removable Flash Storage Card	Pollard	A210
11. Hach Fluoride Pocket Colorimeter II Test Kit	Hach	5870005
12. SPADNS Fluoride Reagent Solution, 1 L	Hach	44453
13. Fluoride Standard Solution, 1.0 mg/L as F(NIST)	Hach	29149
14. Deionized Water, 4L	Hach	27256
15. Pipet Filler, Safety Bulb	Hach	1465100
16. Pipet Volumetric Class A, 10mL	Hach	1451538
17. Pipet Volumetric Class A, 2mL	Hach	1451536
18. SPADNS 2 Fluoride Reagent AccuVac Ampules	Hach	2527025
19. Gate Valve, Size 3/4 In, FNPT Connection	Grainger	6NP02
20. HoseAdapter, Brass 2.5 NH F x 3/4 NPT ML	Grainger	6APC5
21. W-23XD Dual Probe Ion Detector	HORIBA	
22. W-21XD Single Probe water quality logger	HORIBA	
23. Grab Sampling Bottles 250 mL	KGS Lab	

The figures shown on the next four pages encompass all the equipment that will be utilized for the hydraulic calibration. Refer to each items supplier's website for more information regarding the equipment. The following websites are as follows:

www.pollardswater.com

www.hach.com

www.grainger.com

www.horiba.com

www.uky.edu/KGS

Figure F.1 Hydrant Flow Gauge

Figure F.2 Hydrant Static Pressure Gauge

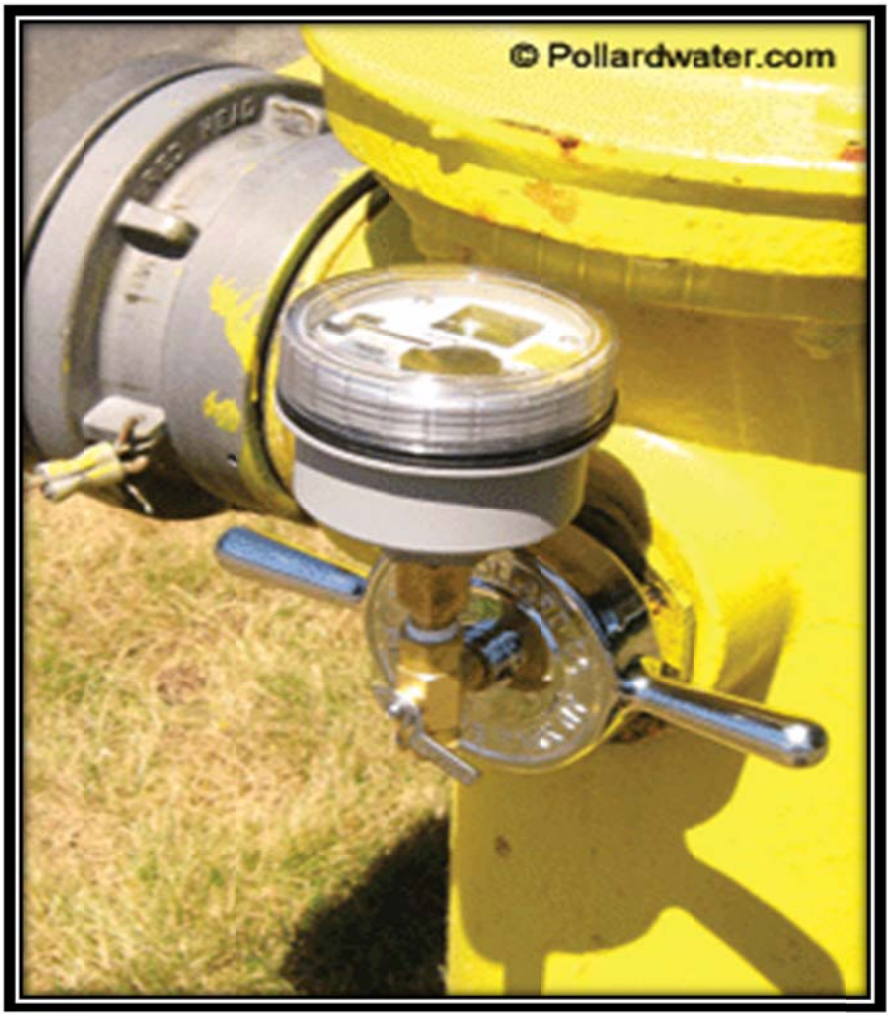


Figure F.3a Continuous Pressure Recorder

Figure F.3b Software and Download Cable

Figure F.3c Removable Flash Drive

Figure F.4 Dechlorinating Diffuser with Pitot Gauge

Figure F.4b Dechlorinating Tablets

Figure F.5 Pressure Snubbers

Figure F.6 Hydrant Wrenches

Figure F.7 Hach Fluoride Pocket Colorimeter II Test Kit

Figure F.8 SPADNS Fluoride Reagent Solution, 1 L

Figure F.9 Fluoride Standard Solution, 1.0 mg/L as F (NIST)

Figure F.10 Deionized Water

Figure F.11 Pipet Filler, Safety Bulb

Figure F.12 Pipet Class A, 10 mL

Figure F.13 Pipet Class A, 2mL

Figure F.14 SPADNS 2 (Arsenic-free) Fluoride Reagent AccuVac® Ampules

Figure F.15 Gate Valve with Brass Hydrant Hose Adapter

Figure F.16 Grab Sampling Bottle

Figures 15 through 18 depict images of the equipment that were taken during the Camp Lejeune Tracer Study. The same equipment may be utilized for the current tracer study

Figure F.17 HORIBA W-23XD dual Probe Ion detector with A) Fluoride and chloride sensors and B) pH, temperature and conductivity sensors

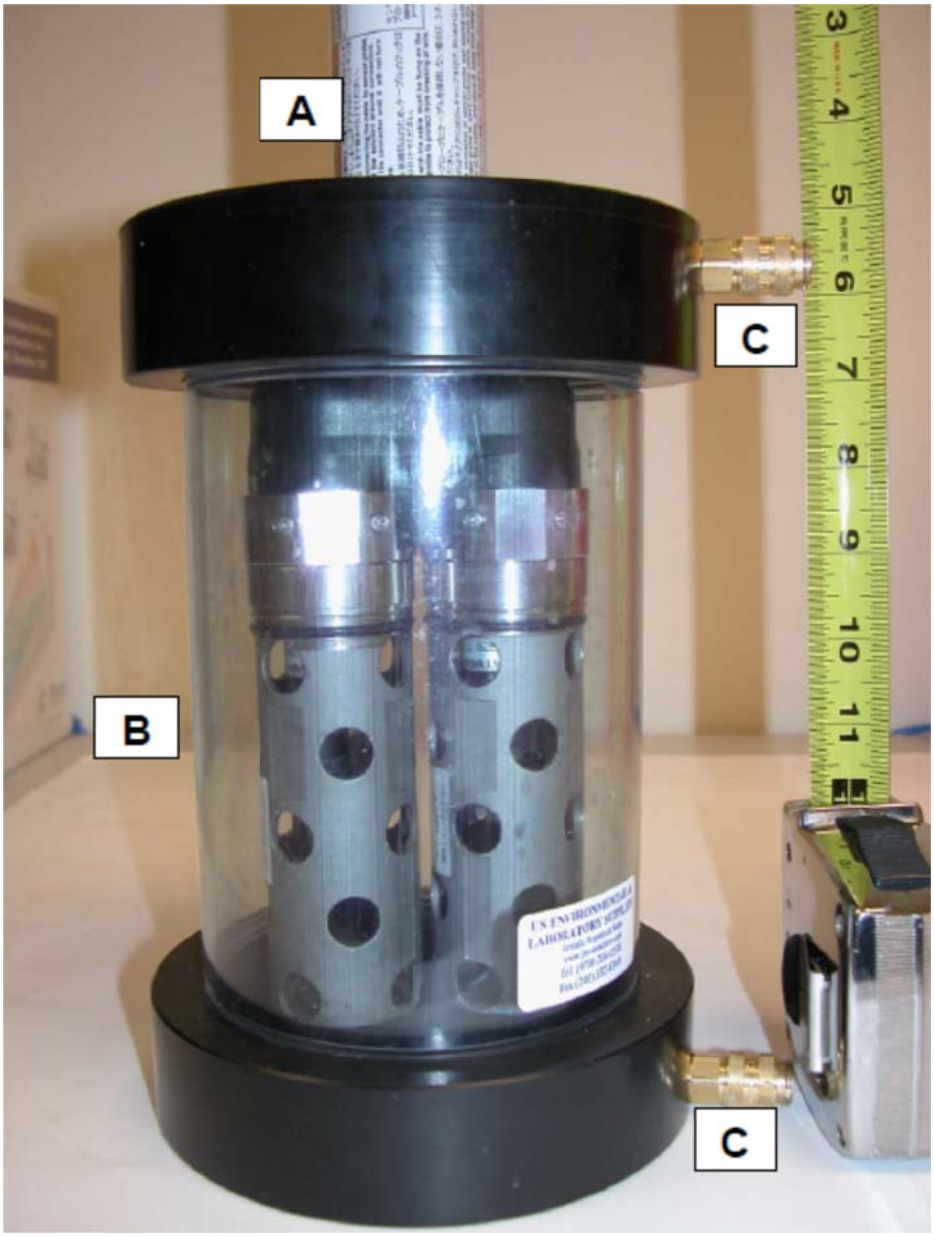


Figure F.18 A) HORIBA W-23XD dual probe ion detector (B) Flow cell with (C) Rectus 21KANNMPX, ¼ NPT brass connectors

Figure F.19 HORIBA W-23XD water-quality Control Unit and Cable Attached to dual probe ion detector.

Figure F.20 (A)HORIBA W-21XD single probe water-quality measurement logger (B) control unit for downloading data from logger and (C) cable to connect control unit to probe

Appendix G: SW846-9056 Method for Fluoride Testing

The method used for Fluoride testing at the Kentucky Geology Survey (KGS) Lab is shown below. This will be the method used to analyze fluoride samples taken from the field.

Ion Chromatography of Water

1. Discussion

Principle

This method addresses the sequential determination of the following inorganic anions: *bromide, chloride, fluoride, nitrate, Kjeldahl nitrogen, total nitrogen* and *sulfate*. A small volume of water sample is injected into an ion chromatograph to flush and fill a constant volume sample loop. The sample is then injected into a stream of carbonate-bicarbonate eluent. The sample is pumped through three different ion exchange columns and into a conductivity detector. The first two columns, a precolumn (or guard column), and a separator column, are packed with low-capacity, strongly basic anion exchanger. Ions are separated into discrete bands based on their affinity for the exchange sites of the resin. The last column is a suppressor column that reduces the background conductivity of the eluent to a low or negligible level and converts the anions in the sample to their corresponding acids. The separated anions in their acid form are measured using an electrical conductivity cell. Anions are identified based on their retention times compared to known standards. Quantitation is accomplished by measuring the peak area and comparing it to a calibration curve generated from known standards.

Sensitivity

Ion Chromatography values for anions ranging from 0 to approximately 40 mg/L can be measured and greater concentrations of anions can be determined with the appropriate dilution of sample with deionized water to place the sample concentration within the working range of the calibration curve.

Interferences

Any species with retention time similar to that of the desired ion will interfere. Large quantities of ions eluting close to the ion of interest will also result in interference. Separation can be improved by adjusting the eluent concentration and /or flow rate. Sample dilution and/or the use of the method of Standard Additions can also be used. For example, high levels of organic acids may be present in industrial wastes, which may interfere with inorganic anion analysis. Two common species, formate and acetate, elute between fluoride and chloride. The water dip, or negative peak, that elutes near, and can interfere with, the fluoride peak can usually be eliminated by the addition of the equivalent of 1 mL of concentrated eluent (100X) to 100 mL of each standard and sample. Alternatively, 0.05 mL of 100X eluent can be added to 5 mL of each standard and sample.

Because bromide and nitrate elute very close together, they can potentially interfere with each other. It is advisable not to have Br-/NO_3- ratios higher than 1:10 or 10:1 if both anions are to be quantified. If nitrate is observed to be an interference with bromide, use of an alternate detector (e.g., electrochemical detector) is recommended.

Method Interferences may be caused by contaminants in the reagent water, reagents, glassware, and other sample processing apparatus that lead to discrete artifacts or elevated baseline in ion chromatograms. Samples that contain particles larger than 0.45 micrometers and reagent solutions that contain particles larger than 0.20 micrometers require filtration to prevent damage to instrument columns and flow systems. If a packed bed suppressor column is used, it will be slowly consumed during analysis and, therefore, will need to be regenerated. Use of either an anion fiber suppressor or an anion micro-membrane suppressor eliminates the time-consuming regeneration step by using a continuous flow of regenerant.

Because of the possibility of contamination, do not allow the nitrogen cylinder to run until it is empty. Once the regulator gauge reads 100 kPa, switch the cylinder out for a full one. The old cylinder should them be returned to room #19 for storage until the gas company can pick it up. Make sure that the status tag marks the cylinder as "EMPTY".

Sample Handling and Preservation
Samples should be collected in glass or plastic bottles that have been thoroughly cleaned and rinsed with reagent water. The volume collected should be sufficient to ensure a representative sample and allow for replicate analysis, if required. Most analytes have a 28 day holding time, with no preservative and cooled to $4^{o}C$. Nitrite, nitrate, and orthophosphate have a holding time of 48 hours. Combined nitrate/nitrite samples preserved with H_2SO_4 to a pH $\leq$2 can be held for 28 days; however, pH$\leq$2 and pH$\geq$12 can be harmful to the columns. It is recommended that the pH be adjusted to pH$\geq$2 and pH$\leq$12 just prior to analysis.

Note: Prior to analysis, the refrigerated samples should be allowed to equilibrate to room temperature for a stable analysis.

2. Apparatus

Dionex DX500
Dionex CD20 Conductivity Detector
Dionex IP25 Isocratic Pump(used with System 1 for Fluoride analysis)
Dionex GP50 Gradient Pump
Dionex Eluent Organizer
Dionex AS40 Automated Sampler
Dionex ASRS-Ultra Self-Regenerating Suppressor
Dionex Ionpac Guard Column (AG4A, AG9A, or AG14A)
Dionex Ionpac Analytical Column (AS4A, AS9A, or AS14A)
Dionex PeakNet 6 Software Package
Dionex 5 mL Sample Polyvials and Filter Caps
2 L Regenerant Bottles
5 mL Adjustable Pipettor and Pipettor Tips
1 mL Adjustable Pipettor and Pipettor Tips
A Supply of Volumetric Flasks ranging in size from 25 mL to 2 L
A Supply of 45 micrometer pore size Cellulose Acetate Filtration Membranes
A Supply of 25x150 mm Test Tubes
Test Tube Racks for the above 25x150 mm Test Tubes
Gelman 47 mm Magnetic Vacuum Filter Funnel, 500 mL Vacuum Flask, and a Vacuum Supply

3. Reagents

Purity of Reagents—HPLC grade chemicals (where available) shall be used in all reagents for Ion Chromatography, due to the vulnerability of the resin in the columns to organic and trace metal contamination of active sites. The use of lesser purity chemicals will degrade the columns.

Purity of Water—Unless otherwise indicated, references to water shall be understood to mean Type I reagent grade water (Milli Q Water System) conforming to the requirements in ASTM Specification D1193.

Eluent Preparation for **SYS 2 AS4A** *Methods, including Bromides (using AG4, AG4 and AS4 columns)*—All chemicals are predried at 105° C for 2 hrs then stored in the desiccator. Weigh out 0.191 g of sodium carbonate (Na_2CO_3) and 0.286 g of sodium bicarbonate ($NaHCO_3$) and dissolve in water. System 2 (the chromatography module that contains the AG4, AG4, and AS4 Dionex columns) to be sparged, using helium, of all dissolved gases before operation.

Eluent Preparation for **AS14COLPN** (Fluoride) *Method (using AG14 and AS14 columns)*— Weigh out 0.3696 g of sodium carbonate (Na_2CO_3) and 0.080 g of sodium bicarbonate (NaHCO3) and dissolve in water. Bring the volume to 1000 mL and place the eluent in the System 1 bottle marked for this eluent concentration. The eluent must be sparged using helium as in the above reagent for System 2.

Eluent Preparation for **AS4ACOLTKN** (TKN) *Methods, including Total Nitrogen (using AG4A, AG4A, and AS4A columns)*—Weigh out 0.191 g of sodium carbonate (Na_2CO_3) and 0.143 g of sodium bicarbonate ($NaHCO_3$) and dissolve in water. Bring the volume up to 1000 ml and place in the System 2 bottle labeled "*IC-TKN 0.191/0.143*". Sparge the eluent as in the above reagent for System 2.

100X Sample Spiking Eluent—prepared by using the above carbonate/bicarbonate ratios, but increasing the concentration 100X. Weigh out 1.91 g of Na_2CO_3 and 2.86 g of $NaHCO_3$ into a 100 mL volumetric flask. 0.05 mL of this solution is added to 5 mL of all samples and standards to resolve the water dip associated with the fluoride peak.

Stock standard solutions, 1000 mg/L (1 mg/mL): Stock standard solutions may be purchased (SPEX) as certified solutions or prepared from ACS reagent grade materials (dried at 105^{o} C for 30 minutes

Calibration Standards—for the **SYS 2 AS4A** (except Bromide) methods are prepared as follows:

1. *Calibration Standard 1:* Pipette 0.1 mL of 1000 mg/L $NaNO_3$ stock standard, 0.1 mL of 1000 mg/L NaF stock standard, 2 mL of 1000 mg/L NaCl stock standard, and 10 mL of 1000 mg/L K_2SO_4 stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.
2. *Calibration Standard 2*: Pipette 0.5 mL of 1000 mg/L $NaNO_3$ stock standard, 0.5 mL of 1000 mg/L NaF stock standard, 5 ml of 1000 mg/L NaCl stock standard, and 20 mL of 1000 mg/L K_2SO_4 stock standard into a 1000 mL volumetric flask, partially filled with water, then fill to volume.
3. *Calibration Standard 3*: Pipette 2.5 mL of 1000 mg/mL $NaNO_3$ stock standard, 2.5 mL of 1000 mg/L NaF stock standard, 10 mL of 1000 mg/L NaCl stock standard, and 40 mL of 1000 mg/L K_2SO_4 stock standard into a 1000 mL volumetric flask partially filled with deionized water, then fill to volume.
4. *Quality Control Sample:* Pipette 1.0 mL of 1000 mg/L $NaNO_3$ stock solution, 1.0 mL of 1000 mg/L NaF stock solution, 8 mL of 1000 mg/L NaCl stock solution, and 30 mL of mg/L K_2SO_4 stock standard into a 1000 mL volumetric flask, partially filled with water, then fill to volume.

Calibration Standards—for the **AS14COLPN** (Fluoride) method are prepared as follows:

1. *Calibration Standard 1*: Pipette 0.01 mL of 1000 mg/L NaF stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.
2. *Calibration Standard 2*: Pipette 0.05 mL of 1000 mg/L NaF stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.

3. *Calibration Standard 3*: Pipette 0.1 mL of 1000 mg/mL NaF stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.
4. *Calibration Standard 4*: Pipette 0.5 mL of 1000 µg/mL NaF stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.
5. *Calibration Standard 5*: Pipette 1.0 mL of 1000 mg/L 1000 stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.
6. *Quality Control Standard*: Pipette 0.1 mL of 1000 mg/L NaF from a separate source stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.
7. *Quality Control Standard*: Pipette 0.4 mL of 1000 mg/L NaF from a separate source stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.
8. *Quality Control Standard*: Pipette 1.0 mL of 1000 mg/L NaF from a separate source stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volum

Calibration Standards—for the **SYS 2 AS4A** (Bromide) method are prepared as follows:

1. *Calibration Standard 1*: Pipette 2 mL of 1000 mg/L NaBr stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.
2. *Calibration Standard 2*: Pipette 5 mL of 1000 mg/L NaBr stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.
3. *Calibration Standard 3*: Pipette 10 mL of 1000 mg/L NaBr stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.
4. *Quality Control Standard*: Pipette 8 mL of 1000 mg/L NaBr stock standard into a 1000 mL volumetric flask partially filled with water, then fill to volume.

Outside Source Certified Quality Control Sample—ERA

4. Procedure

A. Instrument Preparation

1. Before turning on the Dionex Ion Chromatography System:
   a. Fill the eluent reservoir(s) with fresh eluent.
   b. Make certain the waste reservoir is empty of all waste.
   c. Turn on the helium. The system pressure should be between 7 - 15psi. The system pressure can be regulated with the knob on the back of the Eluent Organizer.
   d. Connecting a piece of tubing to the gas line going into the eluent bottle and putting the tubing into the eluent degasses the eluent reservoir(s). The gas knob on the Eluent Organizer that corresponds to the eluent bottle should be slowly opened until a constant bubbling stream can be seen in the eluent bottle.
   e. The eluent should be degassed with helium, for a minimum of 30 minutes, before operation of the instrument.
   f. After the eluent has been degassed, remove the tube from the eluent and tightly seal the eluent bottle. The eluent is now ready to introduce into the system.
2. Whether using the IP25 for Fluorides or the GP50 for everything else, turn off the browser, scroll to **REMOTE** on the screen, select **LOCAL** and **ENTER**.
3. Scroll to mL/min., change to 0 mL/min., and hit **ENTER**. If using the IP25 pump, skip to step #5.
4. Hit **MENU** and select **1**, then **ENTER**.
5. Insert syringe into the Priming Block, open the gas valve on the Eluent Organizer, turn the valve on the Priming Block counterclockwise, and turn on the pump that corresponds with the method to be ran by pushing the **OFF/ON** button.
6. If the syringe does not fill freely, assist by gently pulling back on the plunger of the syringe. Make certain that all of the air bubbles are removed from the eluent line to the pumps.
7. Press **OFF/ON** on the pump to turn it off.
8. Turn the valve on the Priming Block clockwise, remove the syringe and expel the air bubbles from the syringe.

9. Reinsert the syringe filled with eluent into the Priming Block.
10. Open the valve on the Pressure Transducer and the valve on the Priming Block with the eluent filled syringe still attached. This is accomplished by turning both counterclockwise.
11. Press **PRIME** on the pump and push the contents of the syringe into the Priming Block. After the eluent has been injected into the Priming Block, press **OFF/ON** to turn the prime pump off and to close the valves on the Pressure Transducer and Priming Block.
12. Remove the syringe from the Priming Block.
13. Scroll to the mL/min. on the screen for the pump. For the GP50, type 2 mL/min., and press **ENTER**. For the IP25, type 1.2 mL/min., and press **ENTER**.
14. Press **OFF/ON** to turn on the pump at the appropriate rate. The pressure should soon stabilize between both pumpheads after two minutes of pumping time.
15. If the pressure between pumpheads has a difference >20 psi, then shut down the pump and repeat steps 2-14 to remove air bubbles and prime the pumps.
16. Once the pump has a pumping pressure difference between pumpheads of <20 psi, then go to the computer and enter PeakNet.
17. On the computer**, turn on the Peaknet 6 browser**, then choose either **System 1** (Fluoride) or **System 2** (all other anions including Bromide and TKN).
18. Go to **last run sequence, click to highlight and go to file, click save as.**. This will load the method of interest and a template for the current sequence run.
19. The sequence is edited to reflect the method and samples that are to be run.
    a. **AS14COLPN** for Fluoride
    b. **SYS 2 AS4A** for Bromides
    c. **AS4ACOLTKN** for TKN and Total Nitrogen

Note: Data is reprocessed in the section of PeakNet 6 called *Sequence integration editor.* Only operators with a <u>minimum of three months</u> experience in Ion Chromatography should attempt to reprocess data for this analysis. Once data is optimized, then the nitrogen values from nitrate and nitrite analysis can be subtracted from this value for the TKN nitrogen value. If only Total Nitrogen is needed then use the optimized data value without the correction for nitrite and nitrate nitrogen.

    d. **SYS 2 AS4A** for all other anions,
20. Observe the reading on the screen of the CD20 Conductivity Detector. A conductivity rate change of <0.03 μS over a 30 second time span is considered stable for analysis.
21. If using the GP50 pump, it will take about 15-30 minutes for the CD20 system to stabilize. If using the IP25, it will take between 30 minutes to 2 hours for stabilization.
22. Once the CD20 is stabilized, the Dionex DX500 Ion Chromatography System is ready to start standardization.

NOTE: When using the GP50 Gradient Pump, all due care must be taken before one switches from local procedures to remote procedures. The bottle from which the eluent is being pumped (i.e., A, B, C, or D) must exactly match the bottle specified in the method. If there is a difference, then once the pump control is turned over to remote control, irreversible damage and destruction of suppressors, columns, piston seals, and check valves on the GP50 Gradient Pump will occur. <u>NEVER</u> switch from bottle C to A, B, or D without flushing the system lines with water to remove all traces of eluent from bottle C from the lines.

B. <u>Sample Preparation</u>
1. If the sample was not filtered in the field, it must be done so now. Transfer 50 mL of a well-mixed sample to the filtering apparatus. Apply the suction and collect the filtrate.

2. If the conductivity values for the sample are high, dilution will be necessary to properly run the sample within the calibration standard range. Dilutions are made in the Polyvials with the plastic Filter Caps. If the dilutions are > 20X, then volumetric glassware is required.
3. All dilutions are performed with reagent grade DI water. Be sure to mix the dilution well.
4. For Fluorides and Bromides, pipette 5.0 mL of the filtered samples into the Polyvials. For all other anions, including TKN and Total Nitrogen, first pipette 0.05 mL of 100X sample spiking eluent into the Polyvials, then pipette 4.95 mL of the filtered samples on top of the spiking eluent.
5. The Filter Caps are pressed into the Polyvials using the insertion tool.
6. Place the Polyvials into the Sample Cassette, which is placed into the Autosampler.
7. The white/black dot on the Sample Cassette should be located on right-hand side when loaded in the left-hand side of the Automated Sampler for System 2.
8. For every ten samples the following should be included:
   a. 1 DI water blank
   b. 1 Duplicate of any one sample
   c. 1 Quality Control sample/calibration check

C. Calibration and Sample Analysis

1. Set up the instrument with proper operating parameters established in the operation condition procedure
2. The instrument must be allowed to become thermally stable before proceeding. This usually takes 1 hour from the point on initial degassing to the stabilization of the baseline conductivity.
3. To run samples on the Dionex Ion Chromatography System:
   a. Make a run schedule on the PeakNet Software Section labeled **SEQUENCE**.
   b. Double click the mouse on the **SYS 1 or SYS 2** to display the Scheduler Area. The name of the calibration standards must be entered under the sample name section as **Standard #1, Standard #2**, and **Standard #3**.

   Note: Level must be changed to the corresponding standard level or the calibration will be in error. (Example: Standard #1 = Level #1; Standard #5 = Level #5)

   c. Next, enter QC, blanks, QC, samples, duplicates, QC, and blanks, in that order.
   d. Under sample type, click on either **Calibration Standard** or **Sample**, depending on what is being run.
   e. Under the **Method** section, the method name must be entered. To do so, double click on the highlighted area under **Method**, scroll through the list of methods and double click on the method of interest.
   f. Next under the **Data File** section, enter the name of the data file.
   g. Finally, in the **Dil** area, type in the dilution factor if different from 1. Do this for all standards, blanks, quality controls, duplicates, and samples to be run under this schedule.
   h. Save the schedule and obtain a printout of it.
   i. Standardize the Dionex Ion Chromatography System by running the standards: **Standard #1**, **Standard #2**, and **Standard #3**.
4. Run the QC standards.
5. Run the prepblank and DI water blank.
6. Run the samples, duplicates, and blanks.
7. Run the QC standards at the end.

5. Calculations

A. Calculations are based upon the ratio of the peak area and concentration of standards to the peak area for the unknown. Peaks at the same or approximately the same retention times are compared. Once the method has been updated with the current calibration, this is calculated automatically by the software using linear regression. Remember that when dilutions are being run, the correct dilution factor must be entered.

B. Manual calculations are based upon the ratio of the peak and concentration of standards to the peak area for the unknown when the software will not automatically calculate the unknown concentration. Peaks at the same or approximately the same retention times are compared. The unknown concentration can be calculated from using this ratio. Remember that when dilutions are being run that the correct dilution factor must be entered before you will get the correct result.

C. When possible the unknown should be bracketed between two knowns and the calculation of the unknown made from both for comparison.

6. Quality Control

A quality control sample obtained from an outside source must first be used for the initial verification of the calibration standards. A fresh portion of this sample should be analyzed every week to monitor stability. If the results are not within +/- 10 % of the true value listed for the control sample, prepare a new calibration standard and recalibrate the instrument. If this does not correct the problem, prepare a new standard and repeat the calibration. A quality control sample should be run at the beginning and end of each sample delivery group (SDG) or at the frequency of one per every ten samples. The QC's value should fall between ± 10 % of its theoretical concentration.

A duplicate should be run for each SDG or at the frequency of one per every twenty samples, whichever is greater. The RPD (Relative Percent Difference) should be less than 10%. If this difference is exceeded, the duplicate must be reanalyzed.

From each pair of duplicate analytes (X_1 and X_2), calculate their RPD value:

$$\% \; RPD = 2 \bullet \left(\frac{X_1 - X_2}{X_1 + X_2} \right) x \, 100$$

where:

(X_1 - X_2) means the absolute difference between X_1 and X_2.

7. Method Performance

The method detection limit (MDL) should be established by determining seven replicates that are 2 to 5 times the instrument detection limit. The MDL is defined as the minimum concentration that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the analyte.

$$MDL = t_{(n-1,1-\alpha\,=99)}(S)$$

where:

t = the t statistic for n number of replicates used (for n=7, t=3.143)

n = number of replicates
S = standard deviation of replicates

8. Reference

EPA SW 846-9056, Chapter 5, September 1994

U.S. EPA Method 300.0, March 1984

ASTM vol. 11.01 (1996), D 4327, “Standard Test Method for Anions in Water by Chemically
Suppressed Ion Chromatography”.

Appendix H: Guideline for Obtaining a Representative Sample for Optimization-Version 5

This Appendix describes the general guidelines that should be used for obtaining a good representative sample of fluoride during the tracer study field tests. This document was produced by the US EPA Technical Support Center.

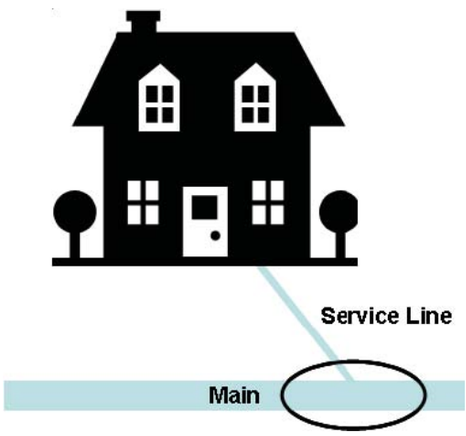
Distribution System Guideline for Obtaining a Representative Sample For Optimization

Objective

It is im portant for water systems pursuing optimization to have a good understanding and accurate characterization or "picture" of water quality in all areas of their distribution system. Developing this "picture" allows the system to:

- Assess water quality relative to optimization performance goals.
- Understand where critical areas of the system are located (e.g., areas with potential for increase microbial activity or Disinfectant By Product (DBP) formation).
- Identify anomalies in water quality data that may indicate contamination, cross connection, impacts of tank or DS operations, etc.

This guidance is intended to help systems establish a consistent, technically sound approach for collecting a representative water quality sample in the distribution system. In this context, a representative sample should accurately capture the water in the distribution system main, not the service line, immediately adjacent to the sample location[1]. As such, the water that is located in the service line or piping from the home/business/ hydrant to the main should be wasted or "flushed″ before a sample is collected so that the sampler can ensure that he/she is sampling water from the distribution system main (see Figure below). The sampler should avoid over-flushing, as this may draw water from another area of the distribution system, which would not represent the water quality at the intended sample site, thus skewing the "picture″ of the water quality at that location in the distribution system.



1. This guideline is intended for water systems where the customer owns the service line beyond the meter. However, if the responsibility of the water system includes the service line and premise plumbing (e.g., privately owned restaurant or government owned park) or if the sampler desires to collect a sample from the service line or tap to assess water quality, this guideline is not appropriate.

Need for this Guideline

It has been observed that flushing practices prior to sample collection vary dramatically from system to system, but the different approaches seem to have no technical foundation. Many systems use temperature change by "feel" as an indicator that they have flushed the service line. Others wait for a designated time (anywhere from 5 to 15 minutes) at all sample locations before collecting a sample.

Further influencing sampling approaches is the need to get a "good" compliance sample - one that is free of contamination, has an "adequate" chlorine residual, and will not trigger a violation. In order to ensure meeting these criteria, the sampler m ay flush for several minutes or several hours. As a result, the sample could represent water quality somewhere within the distribution, but not at the intended location.

In contrast, a "good" sample for optimization purposes is one that represents the water in the immediate area of the sample site. This guidance is intended to provide a sound, consistent approach for establishing an appropriate sample flush time, which is the first critical step in collecting a representative sample for optimization purposes. Without paying attention to the sample flush times, samplers are inaccurately characterizing their distribution system's water quality and, perhaps, compromising public health.

Approach for Developing this Guideline

A special study was conducted to evaluate and establish this representative sampling guideline. Thirty-eight unique sampling events were conducted and analyzed from two chlorinated distribution systems in Kentucky. Sample taps (residential and business) and hydrants were used for sample sites. Chlorine residual, temperature, and flushing time were used as criteria to determine if adequate flushing had been achieve d and water was coming from the main. Both chlorine residual and temperature were used to indicate the effectiveness of flushing, since these have traditionally been used to indicate flushing effectiveness. Calculated F lush time (CFT) (i.e., theoretical detention time) was determined at each individual site by estimating the pipe length and diameter from the sample tap to the main coupled with a pre-selected flow-rate.

At each sample site, at least three consecutive samples were collected in order to track the changes in chlorine and temperature during the period of flushing. One sample was collected at time zero as soon as the sample tap was opened (to get a baseline), and at least two other samples (one at the calculated flush time and another at twice the calculated flush time). Temperature measurements were read and recorded with a digital temperature probe. Chlorine residual samples were analyzed immediately after the sample was collected using free chlorine AccuVac ampules. Pipe lengths and diameters were estimated using distribution system maps, water system personnel experience, and on-site estimates of pipe lengths (e.g., pacing). Tap and hydrant flow-rates were measured by timing the f ill of a 1-liter bottle or 5-gallon bucket, respectively. Hydrant samples were collected from a hydrant sampling device that was constructed for this purpose.

After each sample event the chlorine and temperature data were analyzed to assess if these values stabilized during the flushing period. It was theorized that temperature and chlorine stabilization could be used as indicators that the water from the service line had been flushed and that the stable readings indicated that the water was coming from the main. The chlorine and temperature readings obtained were then compared relative to the initial sample time, the calculated flush time and to twice the calculated flush time.

The results of the studies indicated that both chlorine and temperature are not consistently reliable indicators that the service line has been flushed. Reasons for the inconsistencies are likely site specific and were not investigated further. Based on this finding, the use of CFT is the suggested approach.

Guideline for Obtaining a Representative Sample

Before a representative distribution system water quality sample can be collected from a distribution system, a sampler must determine an appropriate sample flushing time. The objective of flushing a sample line is to waste or "flush" the water that is in the piping (service line or hydrant) from the home/ business/ hydrant to the main. The determination of this flushing time should ensure that water is coming from the distribution system main in the *immediate area of the identified sample site,* not in the service line or at a non-representative distance from the intended site. The sampler should avoid over-flushing, as this may draw water from another area of the distribution system that would not represent the water quality at the intended sample site.

In general, samplers should take the following steps to ensure that proper flushing has been conducted at the sample site:

1. Estimate the length and diameter of the pipe or hydrant that is to be flushed.
2. Determine CFT based on an estimated pipe length, diameter, and flow-rate (see approaches described below)
3. Open the hydrant or tap, start the timer and, if not using a flow-regulator, verify that the flow is at the desired rate (e.g., by quickly timing the fill of a 5-gallon bucket or liter bottle).
4. At **two times the CFT or time designated by the rule of thumb** (this conservative approach accounts for inaccuracies in flow -rate and piping assumptions) stop flushing and collect the water sample(s). If multiple samples are collected over a significant span of time relative to the flushing time, turn off the tap in between samples.

Hydrant samplers were designed and used by the team in developing this guideline. The hydrant sampler was designed to allow the hydrant to be fully open, while allowing the hydrant to flush at a constant rate (20 gpm) and to permit collecting a sidestream sample. A tap sampler, which regulated the flow to 2 gpm, was also designed.

Note: The estimated CFTs using these tools are not precise measurements since pipe length, diameter, and flow-rate estimates are imprecise. However, these tool s provide a reasonable estimate and a controlled safety factor that should ensure quick, easy determinations and prevent gross overestimation.

Rule of Thumb Approach
The rule of thumb approach is appropriate for sample sites that may only be sampled once (e.g., a sampling study) and have a common configuration relative to the main. For all other sites and sampling needs, the CFT matrix approach is recommended.

> ***Rule of Thumb for Hydrants*** **:** In many cases, the configuration of a hydrant relative to the main is similar from location to location. In other words, if the hydrant type is typical (5 ¼" or 4 ½" main valve opening), lead pipe (horizontal pipe from the main to the hydrant) is 6", and the pipe length is less than approximately 20 feet (typical of a hydrant that is on the same side of the street as the main), the line will flush in approximately 1.5 minutes at 20 gpm. **Assume a 3 minute total flush time for this configuration to allow for an adequate factor of safety**. This conservative flush time should account for flow-rate variations and inaccurate length estimates.
>
> ***Rule of Thumb for Taps:*** Residential service lines are typically ¾ in diameter and less than 100 feet long. A pipe of this diameter will flush up to 100 ft of pipe length in about 1 minute at a flow-rate of about 2 gpm. **Assume a 2 minute total flush time for this configuration to allow for an adequate factor of safety.** This conservative flush time should allow for an adequate safety factor and inaccurate length estimates.

Calculated Flush Time (CFT) Matrix Approach
In all water system s there are sites that are sampled on a routine basis for bacteriological or disinfection byproduct (DBP) compliance sampling. At these sites water system s should establish a unique flush time that is appropriate fo r each sample site, rather than use the rule of thumb at these sites. This flush time can be established ***once*** and be used each time a sample is collected at that location, provided that the piping at this sample site stays the same.

> ***CFT matrix for Hydrants*****:** Determine a conservative CFT from the matrix (Table 1) below using the estimated hydrant and lead pipe lengths and diameters. Guidance on estimating these lengths and diameters is provided in Appendix A. **Collect a sample after the hydrant has flushed for approximately two times the CFT to allow for an adequate factor of safety**.

Table 1. Number of Minutes needed to Flush Hydrant at 20 gpm						
Length of Pipe	Inside (Nominal) Diameter of Hydrant/ Pipe (inches)					
	2	4	6	8	12	16
1	0.0	0.0	0.1	0.1	0.3	0.5
5	0.0	0.2	0.4	0.7	1.5	2.6
10	0.1	0.3	0.7	1.3	2.9	5.2
15	0.1	0.5	1.1	2.0	4.4	7.8
20	0.2	0.7	1.5	2.6	5.9	10.4
25	0.2	0.8	1.8	3.3	7.3	13.1
30	0.2	1.0	2.2	3.9	8.8	15.7
35	0.3	1.1	2.6	4.6	10.3	18.3
40	0.3	1.3	2.9	5.2	11.8	20.9
45	0.4	1.5	3.3	5.9	13.2	23.5
50	0.4	1.6	3.7	6.5	14.7	26.1
55	0.4	1.8	4.0	7.2	16.2	28.7
60	0.5	2.0	4.4	7.8	17.6	31.3
65	0.5	2.1	4.8	8.5	19.1	33.9
70	0.6	2.3	5.1	9.1	20.6	36.6
75	0.6	2.4	5.5	9.0	22.0	39.2
80	0.7	2.6	5.9	10.4	23.5	41.8
85	0.7	2.8	6.2	11.1	25.0	44.4
90	0.7	2.9	6.6	11.8	26.4	47.0
95	0.8	3.1	7.0	12.4	27.9	49.6
100	0.8	3.3	7.3	13.1	29.4	52.2
1. Depending on the type of pipe material and degree of corrosion inside the pipe, the inner diameter will vary. These diameters are meant to be approximations.						

***CFT matrix for Taps*:** Determine a conservative CFT from the matrix (Table 2) below using the estimated service line and premise plumbing lengths and diameters. Guidance on estimating these lengths and diameters is available. **Collect a sample after the tap has flushed for approximately <u>two times the CFT</u> to allow for an adequate safety factor**.

Table 2. Number of Minutes needed to Flush Tap at 2 gpm											
Length of Pipe	Inside (Nominal) Diameter of Pipe (inches)										
	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4
1	0.00	0.01	0.01	0.01	0.02	0.03	0.05	0.1	0.1	0.2	0.3
5	0.01	0.03	0.04	0.1	0.1	0.2	0.2	0.4	0.6	0.9	1.6
10	0.03	0.05	0.08	0.1	0.2	0.3	0.5	0.8	1.3	1.8	3.3
15	0.04	0.08	0.12	0.2	0.3	0.5	0.7	1.2	1.9	2.8	4.9
20	0.1	0.1	0.2	0.2	0.4	0.6	0.9	1.6	2.6	3.7	6.5
25	0.1	0.1	0.2	0.3	0.5	0.8	1.1	2.0	3.2	4.6	8.2
30	0.1	0.2	0.2	0.3	0.6	1.0	1.4	2.4	3.8	5.5	9.8
35	0.1	0.2	0.3	0.4	0.7	1.1	1.6	2.9	4.5	6.4	11.4
40	0.1	0.2	0.3	0.5	0.8	1.3	1.8	3.3	5.1	7.3	13.1
45	0.1	0.2	0.4	0.5	0.9	1.4	2.1	3.7	5.7	8.3	14.7
50	0.1	0.3	0.4	0.6	1.0	1.6	2.3	4.1	6.4	9.2	16.3
55	0.2	0.3	0.4	0.6	1.1	1.8	2.5	4.5	7.0	10.1	18.0
60	0.2	0.3	0.5	0.7	1.2	1.9	2.8	4.9	7.7	11.0	19.6
65	0.2	0.3	0.5	0.7	1.3	2.1	3.0	5.3	8.3	11.9	21.2
70	0.2	0.4	0.6	0.8	1.4	2.2	3.2	5.7	8.9	12.9	22.8
75	0.2	0.4	0.6	0.9	1.5	2.4	3.4	6.1	9.6	13.8	24.5
80	0.2	0.4	0.6	0.9	1.6	2.6	3.7	6.5	10.2	14.7	26.1
85	0.2	0.4	0.7	1.0	1.7	2.7	3.9	6.9	10.8	15.6	27.7
90	0.3	0.5	0.7	1.0	1.8	2.9	4.1	7.3	11.5	16.5	29.4
95	0.3	0.5	0.8	1.1	1.9	3.0	4.4	7.8	12.1	17.4	31.0
100	0.3	0.5	0.8	1.1	2.0	3.2	4.6	8.2	12.8	18.4	32.6
1. If service line diameter is 3" or greater consider selecting a different site as CFT could be long											
2. If plumbing is less than 3/8", assume this pipe volume is negligible											
3. Depending on the type of pipe material and degree of corrosion inside the pipe, the inner diameter will vary. These diameters are meant to be approximations.											

"Cheat Sheets" for estimating the CFT for hydrants and taps, which can be used in the field, are available.

> ***CFT matrix for Other Flowrates*** **:** If the f low-rate is less or greater than that provided in the CFT matrices above, the matrices and calculations provided in Appendix D should be used. **Once the CFT is determined collect a sample after the hydrant/ tap has flushed for <u>two times the CFT</u> to allow for an adequate factor of safety**.

At some sampling locations, a sampler may determine that the CFT matrices are not adequate (i.e., pipe diameter is not included on the table, etc.) and the CFT will need to be calculated.

Other Tips for Representative Sampling

From its experience with distribution system sampling, the optimization team suggests these additional considerations and tips for collecting representative samples in the distribution system:

- Consider sampling from hydrants to allow the system more flexibility in sampling at all areas of the distribution system, even remote sites.
- Sample site s with straightforward, easy-to-estimate piping configurations, such as hydrants and designated sample stations, are preferred.
- A hydrant should *not* be "scoured" by opening and flowing the hydrant in the fully open position before collecting a sample, because this could change the sample's water chemistry (e.g., introducing air into the sample that could impact pH).
- Since dry-barrel hydrants are designed to be opened fully, a hydrant sampling device should be constructed to allow a sampler to fully open the hydrant,
  throttle back the flow to flush at 20 gpm (or desire d flow-rate), and to collect a representative sample. Hydrants should always be opened slowly to minimize hydraulic surges.
- Samplers should be aware of looped portions or distribution locations where two mains come together, because slight over-flushing could pull water from either or both mains or from unknown directions. Understanding the water quality at these sites can be challenging.
- Samplers should use caution, especially when sampling in businesses or homes, where the service line and premise plumbing length is unknown. Any major inaccuracies could significantly over or under-estimate the CFT.
- In cases where premise plumbing length is unknown and an alternative sample site cannot be located, temperature and CFT, together, may indicate when adequate flushing time has been reached. If the CFT isn't long enough, the temperature *may* indicate that a longer flush time is needed. Temperature should stabilize to within 0.2 °C, as indicated by a digital thermometer, between readings. When the CFT has been established it can be documented and used for future sampling at the site.
- If the sampler desires to characterize the water quality in a small area where sample sites could be located next to each other, such as neighboring businesses, CFT should be more carefully estimated in order to avoid over-flushing.
- In cases where the sampler is concerned about over-flushing, the CFT matrix should be used rather than the rule of thumb guidelines.

Based on their experience, the optimization team feels that this guideline is one of the first - of many - steps in a process to increase awareness among distribution system operators about the importance of understanding distribution system water quality and collecting representative samples.

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